Foundation Physics for class X Book 2 for IIT JEE standard 10 by Prof. K K Anand SmartEdu

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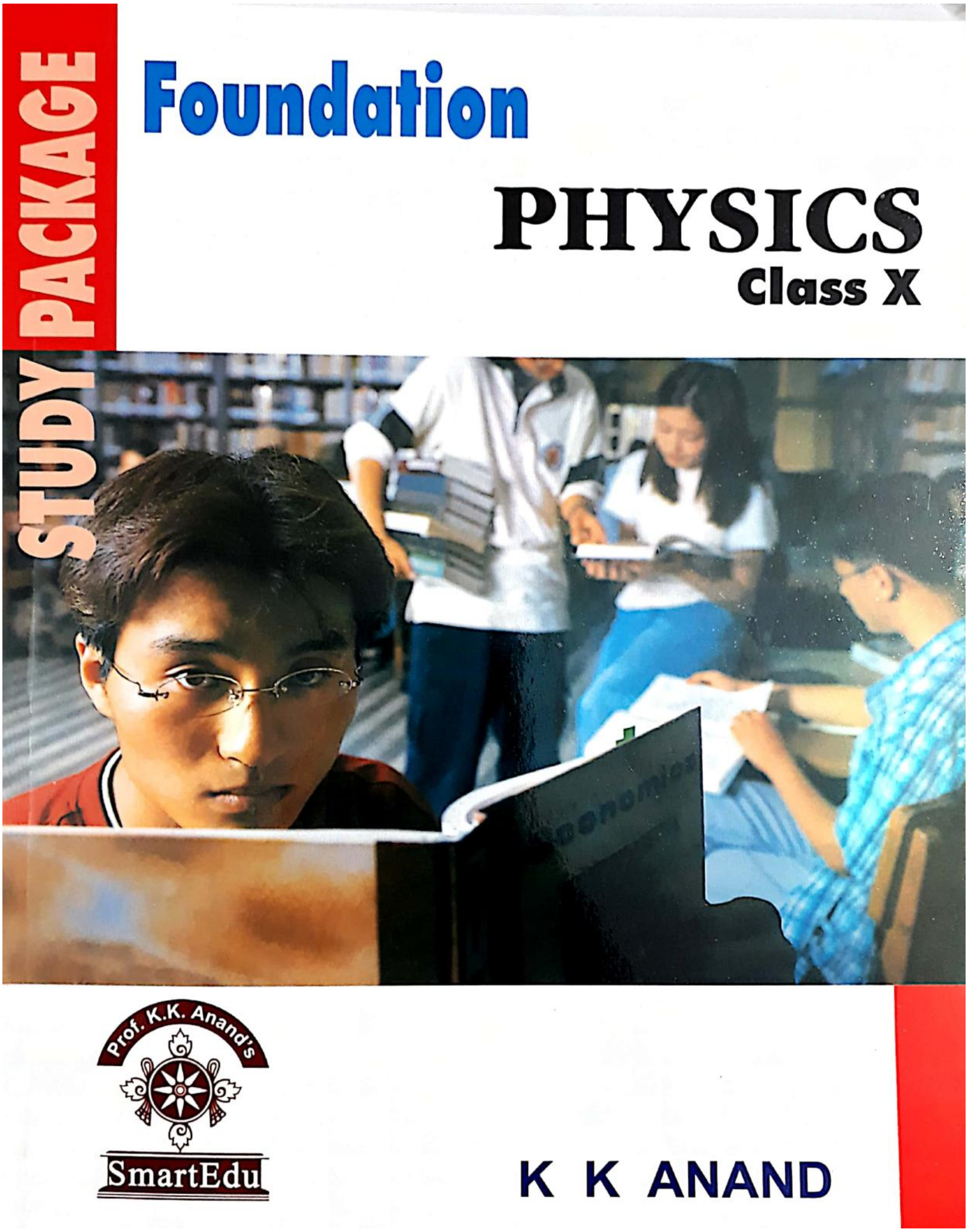
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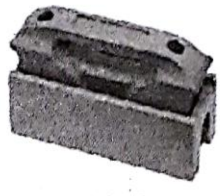
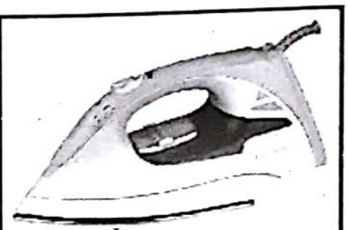
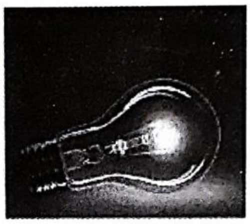
chapter 5



Electric Fuse



Iron



Electric Bulb

Room Heater

HEATING AND CHEMICAL EFFECTS OF CURRENT

Introduction

Heating and chemical effects are the most important effects of electric current. Heating effect has many day-to-day applications for us. We use electric iron to press our clothes, room heater to get rid of cold, electrical lamps to lit our rooms, etc. We access these facilities due to heating effect of current. In these phenomena, electrical energy is converted into heat energy.

The other effect of electric current is to produce the chemical change. This effect is called the chemical effect of electric current. This chapter is based on the two effects of electric current.

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ELECTRIC POWER

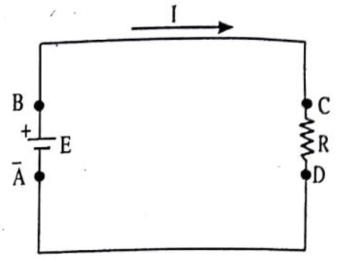

Fig.5.1

If a battery is used to establish an electric current in a conductor, there is a continuous transformation of chemical energy stored in the battery to kinetic energy of the charge carriers. This kinetic energy is quickly lost as a result of collisions between the charge carriers and the lattice ions, resulting in an increase in the temperature of the conductor. Therefore, we see that the chemical energy stored in the battery is continuously transformed into heat energy.

Consider a simple circuit consisting of a battery whose terminals are connected to a resistor R, as shown in figure 5.1.

The positive terminal of the battery (the longer plate) is at the higher potential, while the negative terminal (the shorter plate) is at the lower potential. Now imagine a positive quantity of charge ΔQ moving around the circuit from point A through the battery and resistor and back to A. Point A is a reference point that is grounded, and its potential is taken to be zero. As the charge moves from A to B through the battery, its electrical potential energy increases by an amount $V\Delta Q$ (where V is the potential at B) while the chemical potential energy in the battery decreases by the same amount. However, as the charge moves from C to D through the resistor, it loses this electrical potential energy as it undergoes collisions with atoms in the resistor, thereby producing thermal energy. Note that if we neglect the resistance of the interconnecting wires there is no loss in energy for paths BC and DA. When the charge returns to point A, it must have the same potential energy (zero) as it has at the start.

The rate at which the charge ΔQ loses potential energy in going through the resistor is given by

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t} V = IV$$

where I is the current in the circuit. Of course, the charge regains this energy when it passes through the battery. Since the rate at which the charge loses energy equals the power P lost in the resistor, we have

$$P = IV \qquad \text{............(1)}$$

In this case, the power is supplied to a resistor by a battery. However, eq. (1) can be used to determine the power transferred to any device carrying a current I and having a potential difference V between its terminals.

Using eq. (1) and the fact that $V = IR$ for a resistor, we can express the power dissipated in the alternative forms

$$P = I^2R = \frac{V^2}{R}$$

When I is in amperes, V in volts, and R in ohms, the SI unit of power is the watt (W). The power lost as heat in a conductor of resistance R is called joule heating.

Watt is a small unit of power, its other bigger units are Kilowatt, Megawatt and Horsepower.

$1\ \text{kW} = 1000\ \text{W} = 10^3\ \text{W}$

$1\ \text{MW} = 1000000\ \text{W} = 10^6\ \text{W}$

$1\ \text{hp} = 746\ \text{W}$

If 100W – 220V is written on the bulb then it means that the bulb will consume 100 joule in one second if used at the potential difference of 220 volts.

The value of electricity consumed in houses is decided on the basis of the total electric energy used. Electric power tells us about the electric energy used per second not the total electric energy.

The total energy used in a circuit = power of the electric circuit × time

If the power is in watt and time is in second, then the electric energy will be in joule or watt × second.

As the watt × sec is a small unit of energy, electric energy is measured in Kilowatt Hour (kWh)

1 Kilowatt hour (kWh) = 1000 watt hour

$= 1000 \times 60 \times 60$ watt sec $= 36000000$ joule $= 3.6 \times 10^6$ joule

1 kWh is called the 1 unit.

The electricity department uses this unit in the electric bills. If the 100 watt bulb or any other electric appliance is used for an hour then the total electric energy consumed is 1 kWh or 1 unit.

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CHECK Point

☛ **The wattage marked on a light bulb is not an inherent property of the bulb; rather, it depends on the voltage to which it is connected, usually 110 or 120V. How many amperes flow through a 60-W bulb connected in a 120-V circuit?**

SOLUTION

Using the formula,
Watt = volt × ampere

or, $60 = 120 \times \text{ampere} \Rightarrow \text{ampere} = \dfrac{60}{120} = 0.5A$

Thus, a 0.5 A current flows through a 60-W bulb connected in a 120-V circuit

ILLUSTRATION 5.1

An immersion rod of 1500 W is used everyday for 3 hours to boil water. If the rate of 1 unit of electric energy is ₹ 2.5 then what will be the total cost of the electricity used in 30 days ?

SOLUTION:

Electric energy used in a day = 1500 × 3 Wh = 4500 Wh
Electric energy used in 30 days = 4500 × 30 Wh = 135000 Wh

Total energy in kWh unit = $\dfrac{135000}{1000}$ kWh = 135 kWh or unit

Hence the total cost of the electricity = 135 × ₹2.50 = ₹ 337.50

ILLUSTRATION 5.2

An electric heater is rated 750 W – 200V. Calculate (i) resistance of the heating element (ii) current flowing through it.

SOLUTION:

$P = 750$ W, $p.d. = 200V$, $R = ?$, $I = ?$

$$P = \frac{V^2}{R} \quad \therefore \; R = \frac{V^2}{P}$$

$$\therefore \; R = \frac{200 \times 200}{750} = 53.33\,\Omega$$

$$R = \frac{V}{I} \quad \therefore \; I = \frac{V}{R} = \frac{200}{53.33} = 3.75\text{ A}$$

ILLUSTRATION 5.3

Calculate the monthly bill for a heater of resistance 50Ω, which used 200V mains, such that its daily use is 4 hr. The energy costs ₹ 2.50 per kWh.

SOLUTION:

Power of heater $P = \dfrac{V^2}{R} = \dfrac{(200)^2}{50} = 800W$

∴ Energy consumed by heat in a day = $P \times t$ = 800W × 4 h = 3200 Wh

∴ Energy consumed by heater in 30 days (month) = 3200 Wh × 30 = 96000 Wh = 96 kWh

∴ Monthly bill = 96 kWh × $\dfrac{₹\ 2.50}{\text{kWh}}$ = ₹ 240

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ILLUSTRATION–5.4

Rearrange the equation

Current = voltage/ resistance

to express *resistance* in terms of current and voltage. Then solve the following: A certain device in a 120-V circuit has a current rating of 20 A. What is the resistance of the device (how many ohms)?

SOLUTION :

Current = voltage / resistance

Rearranging, we get

Current × resistance = voltage

or, Resistance = voltage/current.

Now,Resistance = $\frac{\text{voltage}}{\text{current}} = \frac{120}{20} = 6$ ohms.

Therefore, the resistance of the device is 6 ohms.

HEAT PRODUCED DUE TO ELECTRICITY.

When a current passes through a conductor, heat is produced in it due to the collisions between the free electrons and the atoms of the conductor. The heat produced (Q) depends on the following factors.

1. Resistance of conductor : More the resistance of conductor more is the number of collisions between free electrons and atoms. Hence if a conductor offers more resistance $Q \propto R$
2. Current flowing through the conductor : Heat produced increases with the increase in the strength of the current flowing through conductor.
   $Q \propto I^2$
3. Time of flow of current : As the time of flow of current increases, the heat produced also increases.
   $Q \propto t$

Thus a conductor having larger resistance will generate more heat when a stronger current passes through it for a longer time. If I is the current flowing a conductor of resistance R for time t, the heat produced (Q) is given by

$Q \propto I^2Rt$

PRACTICAL APPLICATION OF HEATING EFFECT

The heat generated when current passes through a resistive material is used in many common devices. The material through which the current passes is surrounded by an insulating substance in order to prevent the current from flowing through the cook to the earth when he or she touches the pan. A material that is a good conductor of heat surrounds the insulator.

Hair dryer, in which a fan blows air past heating coils. In this case the warm air can be used to dry hair, but on a broader scale this same principle is used to dry clothes and to heat buildings.

A final example of a household uses the heating effect of electric current is the steam iron. A heating coil warms the bottom of the iron and simultaneously turns water to steam, which is sprayed from jets located in the bottom of the iron.

Other practical application includes heater, toaster, electric kettle.

CHEMICAL EFFECT OF CURRENT

Electric current can produce chemical change. This ability of current is called chemical effect. This effect is shown by D.C. only. A.C. current can't produce chemical effect.

FARADAY'S LAWS OF ELECTROLYSIS

(i) **1st law :** The mass of the substance liberated or deposited at an electrode during electrolysis is directly proportional to the quantity of charge passed through the electrolyte i.e.
mass or $m = Zq = Z\,It$, where Z = electrochemical equivalent (E.C.E.) of substance.

(ii) **2nd law :** When the same amount of charge is passed through different electrolytes, the masses of the substance liberated or deposited at the various electrodes are proportional to their chemical equivalents i.e. $\frac{m_1}{m_2} = \frac{E_1}{E_2}$ where m_1 & m_2 are the masses of the substances liberated or deposited on electrodes during electrolysis and E_1 & E_2 are their chemical equivalents.

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FARADAY CONSTANT

(i) Faraday constant is equal to the amount of charge required to liberate the mass of a substance at an electrode during electrolysis, equal to its chemical equivalent in gram (i.e. one gram equivalent)

(ii) One faraday = $1F = 96500$ C/gram equivalent.

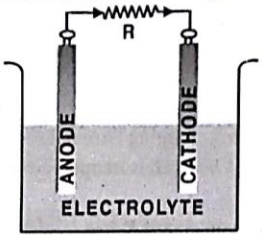

Fig.5.2

ELECTROCHEMICAL CELL

An electrochemical cell is a device which by converting chemical energy into electrical energy maintains the flow of charge in a circuit. It usually consists of two electrodes of different materials and an electrolyte. The electrode at higher potential is called anode and the one at lower potential is cathode

PRIMARY CELLS

The cells which cannot be recharged electrically are called primary cells. Here the original state of cell cannot be brought back by passing electrical energy through cell from external source after cell is discharged.
e.g. Voltaic cell, Daniel cell, Leclanche cell, Manganese-alkaline cell, Mercury button cell etc.

SECONDARY CELLS

The cells in which chemical process is reversible are called secondary cells. Here original chemical state of cell can be brought back by passing electrical energy through cell from external source.
e.g. Lead acid accumulator, alkali cells etc.

ELECTROMOTIVE FORCE (EMF)

The emf of a cell is defined as work done by cell in moving a unit positive charge in the whole circuit including the cell once emf $E = W/q$;
Its SI unit is joule/coulomb or volt.
Emf is the maximum potential difference between the two electrodes of the cell when no current is drawn from the cell. It is the characteristic property of cell and depends on the nature of electrodes and electrolyte used in cell, and is independent of quantity of electrolyte, size of electrodes and distance between the electrodes.

INTERNAL RESISTANCE OF CELL

The opposition offered by the electrolyte of the cell to the flow of electric current through it is called the internal resistance of the cell. The internal resistance of cell depends on.

- Distance between electrodes ($r \propto d$), larger is the separation between electrodes more is the length of electrolyte through which ions have to move so more is internal resistance.
- Conductivity or nature of electrolyte ($r \propto 1/\sigma$)
- Concentration of electrolyte ($r \propto c$), Temperature of electrolyte ($r \propto 1/T$)
- Nature and area of electrodes dipped in electrolyte ($r \propto 1/A$)

TERMINAL POTENTIAL DIFFERENCE

The potential difference between the two electrodes of a cell in a closed circuit i.e., when current is being drawn from the cell is called terminal potential difference.

(a) When cell is discharging

When cell is discharging current inside the cell is from anode to cathode .

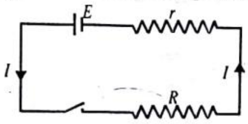

Fig.5.3

Current $I = \dfrac{E}{r+R}$ or $E = IR + Ir = V + Ir$ or $V = E - Ir$

When current is drawn from the cell, potential difference is less than emf of cell. Greater is the current drawn from the cell smaller is the terminal voltage. When a large current is drawn from a cell, its terminal voltage is reduced.

(b) When cell is charging

When cell is charging current inside the cell is from anode to cathode.

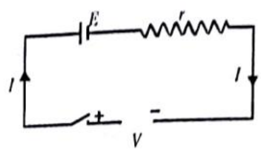

Fig.5.4

Current $I = \frac{V - E}{r}$ or $V = E + Ir$

During charging terminal potential difference is greater than emf of cell.

(c) When cell is in open circuit

In open circuit $R = \infty \therefore I = \frac{E}{R+r} = 0$ So $V = E$

In open circuit terminal potential difference is equal to emf and is the maximum potential difference which a cell can provide.

(d) When cell is short circuited

In short circuit $R = 0$ so $I = \frac{E}{R+r} = \frac{E}{r}$ and $V = IR = 0$

In short circuit current from cell is maximum and terminal potential difference is zero.

(e) Power transferred to load by cell

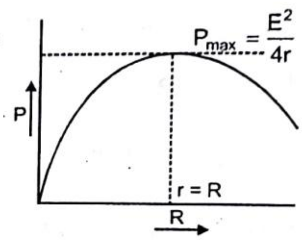

Fig.5.5

$$P = I^2R = \frac{E^2R}{(r+R)^2}$$

$$P = P_{max} \text{ if } r = R$$

Power transferred by cell to load is maximum when $r = R$ and $P_{max} = \frac{E^2}{4r} = \frac{E^2}{4R}$.

DIFFERENCE BETWEEN EMF AND POTENTIAL DIFFERENCE

EMF OF A CELL	POTENTIAL DIFFERENCE
1. The emf of a cell is the maximum potential difference between the two electrodes of a cell when the cell is in the open circuit.	1. The potential difference between the two points is the difference of potential between these two points in a closed circuit.
2. Emf is independent of resistance of circuit and depends upon the nature of electrodes and electrolyte.	2. This depends upon the resistance between two points of the circuit and current flowing through the circuit.
3. The term emf is used for source of current.	3. Potential difference can be measured between any two points of circuit.
4. This is a cause.	4. It is an effect.

ILLUSTRATION 5.5

A dry cell of e.m.f. 1.5 V and internal resistance 0.10Ω s connected across a resistor in series with a very low resistance ammeter. When the circuit is switched on, the ammeter reading settles to a steady value of 2.0 A. What is the steady

(i) rate of chemical energy consumption of the cell.

(ii) rate of energy dissipation inside the cell.

(iii) rate of energy dissipation inside the resistor and

(iv) power output of the source ?

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SOLUTION :

Let R be the external resistance, then

$$(R+r)=\frac{V}{i}=\frac{1.5}{2.0}=0.75\Omega$$

$\therefore R=0.75-r=0.75-0.10=0.65\,\Omega$

(i) The rate of consumption of chemical energy of the cell $= V\times i = 1.5\times2.0 = 3.0\ W$

(ii) The rate of energy dissipation inside the internal resistor $= i^2r = (2.0)^2\times0.10 = 0.4\ W$

(iii) The rate of energy dissipation inside the external resistor $= i^2R = (2.0)^2\times0.65 = 2.6\ W$

(iv) The power output of the source
= total power
− rate of energy dissipation inside the cell
$=3.0-0.4=2.6\ W$

ILLUSTRATION 5.6

Does more current flow out of a battery than into it? Does more current flow into a light bub than out of it? Explain.

SOLUTION :

The current that flow out of a battery is always equal to the current that flow into it.
Similarly, the current that flows into a light bulb is always equal to the current that flows out of it. Although there will be a voltage drop due to the resistance provided to the flow of current due to both the battery and the resistance, but the amount of current won't be affected.

GROUPING OF CELLS

(i) **Series Combination**

The cells are said to be connected in series if negative terminal of first is connected to positive of second whose negative terminal is connected to positive of third cell. The external resistance is connected between free terminals of first and last cells.

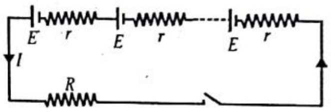

Fig.5.6

Let n identical cells each of emf E and internal resistance r be connected in series. The combination can be replaced by a single cell of emf nE and internal resistance nr. The current flowing through load $I=\frac{nE}{R+nr}$

If $nr << R$ then $I=\frac{nE}{R}$. If equivalent internal resistance nr is less than external resistance R then current in circuit is equal to n times circuit current due to single cell.

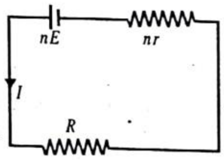

Fig.5.7

If $nr >> R$ then $I = E/r$. If equivalent internal resistance nr is greater than external resistance R then current in circuit is equal to short circuited current obtained from one cell.
Maximum current can be drawn from series combination of cells if external resistance is very large as compared to equivalent internal resistance.
If in series combination of n cells, p cells are reversed then equivalent emf

$$E_{eq}=(n-p)E-pE=(n-2p)E \quad \text{and} \quad r_{eq}=nr \quad \text{So current } I=\frac{(n-2p)E}{nr+R}$$

If unidentical cells are connected in series then

$$E_{eq}=E_1+E_2+.....=\Sigma E_i \quad \text{and} \quad r_{eq}=r_1+r_2+.....=\Sigma r_i.$$

$\therefore$ Current, $I=\frac{\Sigma E_i}{R+\Sigma r_i}$.

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(ii) Parallel Combination

The cells are said to be connected in parallel if positive terminals of all the cells are connected together at one point and their negative terminals at another point. The external resistor is connected between these two points.

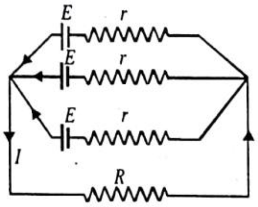

Fig.5.8

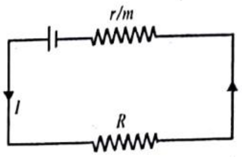

Fig.5.9

Let m identical cells each of emf E and internal resistance r be connected in parallel. The combination can be replaced by a single cell of emf E and internal resistance r/m. The current $I = \dfrac{E}{R + r/m}$.

If $r/m << R$ then $I = \dfrac{E}{R}$. If equivalent internal resistance r/m is less than external resistance R then current in circuit is equal to current produced by a single cell.

If $r/m >> R$ then $I = \dfrac{mE}{r}$. If equivalent internal resistance $\dfrac{r}{m}$ is greater than external resistance then current in circuit is equal to m times the current produced by a short circuited cell.

Thus maximum current can be drawn from parallel combination of cells if external resistance is small as compared to net internal resistance of cells.

(iii) Mixed Combination

If the mn number of identical sources are combined, as shown, where we have the m number of rows of sources in parallel and the n number of sources in series in each row, the total emf of combination becomes ne_s and the total internal resistance of combination becomes nr/m. Then, the electric current through the load is

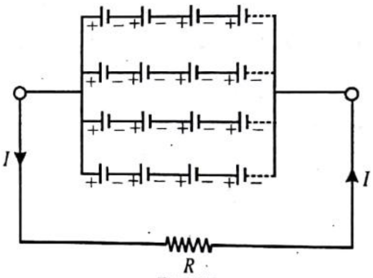

Fig.5.10

$$I = \frac{ne_s}{\left(\frac{nr}{m} + R\right)} = \frac{e_s}{\left(\frac{r}{m} + \frac{R}{n}\right)}$$

and the electrical power delivered to the load is

$$P_2 = RI^2 = R\frac{n^2 e_s^2}{\left(\frac{nr}{m} + R\right)^2} = R\frac{e_s^2}{\left(\frac{r}{m} + \frac{R}{n}\right)^2}$$

which is maximum under the condition of total internal and external resistances being equal, *i.e.*,

$$R = \frac{nr}{m}$$

ILLUSTRATION 5.7

Four identical cells, each of emf $e_s = 2V$, are joined is parallel, providing a current to the external circuit which consists of two resistances, each of 15Ω, in parallel. The terminal voltage of the cells is 1.6 V. Calculate the internal resistance r of each cell.

SOLUTION:

The complete circuit diagram, consisting of the 4 identical cells and the two external resistances in parallel, is shown. The total emf in the circuit is $e_s' = e_s = 2V$, the total internal resistance is $r/4$ and the total external resistance is $15/2 = 7.5\Omega$. Therefore, the current through the total external resistance is

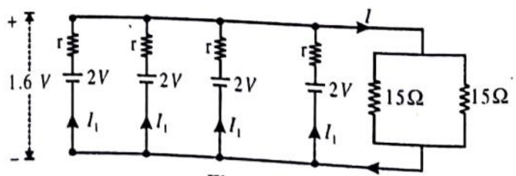

Fig.5.11

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$$I=\frac{2}{\left(\frac{r}{4}+7.5\right)}=\frac{8}{(r+30)}$$

and the terminal voltage across the cells is

$$V=e_s'-I\left(\frac{r}{4}\right)$$

$\Rightarrow$ $$1.6=2-\frac{8}{(r+30)}\times\frac{r}{4}=\frac{60}{(r+30)}$$

$\Rightarrow$ $r=7.5\Omega.$

ILLUSTRATION 5.8

If 64 cells of emf $e_s=2\text{V}$ and internal resistance $r=2\Omega$, are connected in m rows, each consisting of n cells in series, then find out these values of m and n for getting the maximum current through an external resistance $R=8\Omega$.

SOLUTION:

The current through the external resistance R is given by

$$I=\frac{ne_s}{\left(\frac{nr}{m}+R\right)}=\frac{(mn)e_s}{(nr+mR)}=\frac{(64)\times 2}{(n\times 2+m\times 8)}$$

$$=\frac{64}{(n+4m)}=\frac{64}{\left(n+\frac{4\times 64}{n}\right)}=\frac{64}{\left(n+\frac{256}{n}\right)}$$

where $mn=64$ is the total number of cells. The current will be maximum, when the denominator is minimum, *i.e.*, when

$$\frac{d}{dn}\left(n+\frac{256}{n}\right)=0$$

$\Rightarrow$ $$1-\frac{256}{n^2}=0$$

$\Rightarrow$ $n=16$

$\Rightarrow$ $$m=\frac{64}{n}=4.$$

DOMESTIC ELECTRIC CIRCUITS

Electricity from power stations is transmitted to homes through high voltage power lines. Electric potentials as high as 220 000 V AC are used. The electrical potential is decreased to 220 VAC with the help of step-down transformer before it enters the home. A cable containing three colour-coded wires enters the home. One wire is red, one is black, and one is green. The red wires are called live wires (or positive). Another wire with the black insulation is called neutral wires (or negative). There is an electrical potential difference of 220 V AC between a red and a black wire. The earth wire, which has insulation of green colour, is usually connected to a metal plate deep in the earth near the house. This is used as a safety measure, especially for those appliances that have a metallic body, for example, electric press, toaster, table fan, refrigerator, etc. The metallic body is connected to the earth wire, which provides a low-resistance conducting path for the current. Thus, it ensures that any leakage of current to the metallic body of the appliance keeps its potential to that of the earth, and the user may not get a severe electric shock.

Fuses and Circuit Breakers

A fuse is a safety device that acts as a switch. Fuses are connected into the circuit close to the source. As a result all the current flowing in the circuit passes through the fuse. When too much current flows, the fuse heats up sufficiently to bum out. This creates an air gap and no more current flows. The construction of a plug fuse is shown in Figure. Other kinds of fuses are cartridge fuses and knife blade fuses. The essential part is the fuse wire or a blade with a low melting point.

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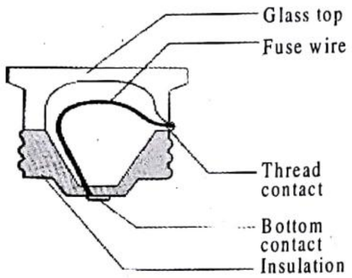

Fig. 5.12 : A plug fuse

Most homes built in recent years use circuit breakers instead of fuses in their electrical panels. A circuit breaker is connected in the same place as a fuse would be, and it performs the same function. Unlike a fuse, however, it does not bum out. When too much current flows, the circuit breaker simply opens like a switch. Then, when the problem that caused the excess current has been corrected, you can close the breaker again.

The Circuit Breaker Panel

At the home, the electricity first passes through an electric meter. The electric meter records the amount of electric energy used in the home. Then the electricity enters a circuit breaker panel. (In some older homes it may enter a fuse panel.) In this panel there is a master circuit breaker. The master circuit breaker can be operated manually to cut off the electricity to the entire home. It opens automatically if the current exceeds the -rated value. In homes that have a 100 A service, the master circuit breaker will allow up to 100 A to pass before it pops open.

There are three strips of conducting metal called bus bars in the breaker panel. The red wire is connected to one, the black wire to another, and the white wire to the third. As a result, two of the bus bars are live and one is neutral.

Electric Circuits in the Home

All the electric circuits within the home originate from the bus bars. Figure shows a 220 V AC cable going to a stove. Notice that the cable is connected to all three bus bars. This cable has two circuit breakers, one for the black wire and one for the red wire. Each major appliance has its own 220 V AC circuit.

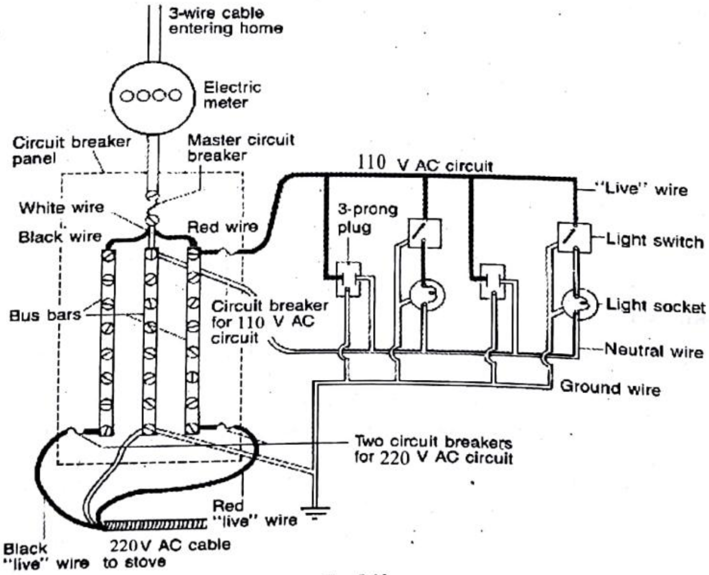

Fig. 5.13

A 110 V AC circuit is also shown. Notice that only two of the bus bars are used, the neutral bus bar and either of the live bus bars. This circuit also has its own circuit breaker. The 110 V AC circuit consists of the circuit breaker, two three-prong plugs, and two light fixtures and two switches. A ground wire connects all switch and outlet boxes to ground and to the neutral bus bar. This prevents injury if the boxes become live.

Loads in the same circuit, such as wall outlets and lights, are always connected in parallel. If one load bums out the others still operate. Also, as more and more loads are turned on, the electrical potential remains the same. However, the electric current increases. But one load does not affect another unless the circuit becomes overloaded.

Causes of Overloaded Circuits

There are two main causes of overloaded circuits. First, an appliance or a conducting wire can develop a short circuit. Now the current is no longer limited by the load. In this case, current passes from the live wire to the neutral wire or from the live wire to the ground wire without passing through the load. The current becomes very large very fast. This heats up the circuit.

Second, too many appliances can be plugged into the same circuit. Each appliance draws a certain current. The combination can draw too much current and the circuit again heats up.

A circuit breaker is designed to prevent overloading. It trips and opens the circuit as soon as the circuit becomes too hot.

CHECK Point

- **Why are devices in household circuits almost never connected in series?**

SOLUTION

The devices in household circuits are never connected in series because if they are connected so they can't be turned on or off separately as required. If one of the device will be turned off then all of them will also be turned off. Moreover, if the devices are lighting one, their brightness will decrease if more devices will be added.

ILLUSTRATION 5.9

An immersion heater having 50Ω resistance is connected to 250V mains. Find the time required to heat 2 kg of water from 34°C to 100°C, assuming there is no loss of heat energy (Sp. heat cap. of water = 4×10^3 J/kg°C)

SOLUTION:

Current passing through the heater

$$I = \frac{V}{R} = \frac{250}{50} = 5A$$

Heat produced = I^2Rt and Heat required = $mC\theta$.

Heat produced = $5^2 \times 50 \times t$

$$mC\theta = 2 \times 4 \times 10^3 \times (100 - 35) = 8 \times 10^3 \times 65$$

Since $5^2 \times 50 \times t = 8 \times 10^3 \times 65$

$$\therefore \quad t = \frac{520 \times 1000}{1250} = 416\text{ s} = 6\text{ min }56\text{ s}$$

ILLUSTRATION 5.10

An electric refrigerator rated 400W operates 8 hours/day. What is the cost of the energy to operate it for 30 days at ₹ 3.00 per kWh ?

SOLUTION:

The total energy consumed by the refrigerator in 30 days would be

400W × 8.0 hours/day × 30 days = 96999 Wh = 96 k Wh

Thus the cost of energy to operate the refrigerator for 30 days is

96 kWh × ₹ 3.00 per kWh = ₹ 288.00

ILLUSTRATION 5.11

What is the operating resistance of a 100-watt household light bulb ? The operating line voltage of household electricity is 120V.

SOLUTION:

Given : P = 100 W, V = 120 V, Find R.

From $P = \frac{V^2}{R}$, We have $R = \frac{V^2}{P} = \frac{(120V)^2}{100W} = 144\ \Omega$

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ILLUSTRATION 5.12

On a 220V power line the powers of two electric bulbs are 60W and 30W separately. Find the powers of their parallel and series combinations when connected on the same line.

SOLUTION:

The resistance of the 220V-60W bulb is $R_1 = \dfrac{V^2}{P_1} = \dfrac{(220)^2}{60}\,\Omega$

The resistance of the 220V-30W bulb is $R_2 = \dfrac{V^2}{P_2} = \dfrac{(220)^2}{30}\,\Omega$

When the bulbs are connected in parallel, their equivalent resistance is $R = \dfrac{R_1 \times R_2}{R_1 + R_2} = \dfrac{\dfrac{(220)^2}{60} \times \dfrac{(220)^2}{30}}{\dfrac{(220)^2}{60} + \dfrac{(220)^2}{30}} = \dfrac{(220)^2}{90}\,\Omega$

The power of the parallel combination is $P = \dfrac{V^2}{R} = \dfrac{(220V)^2}{\{(220)^2/90\}\Omega} = 90W$

When the bulbs are connected in series, their equivalent resistance is $R' = R_1 + R_2 = \dfrac{(220)^2}{60} + \dfrac{(220)^2}{30} = (220)^2 \times \dfrac{1}{20}\,\Omega$

The power is $P' = \dfrac{V^2}{R'} = \dfrac{(220V)^2}{\{(220)^2 \times 1/20\}\Omega} = 20W$

ILLUSTRATION 5.13

An electric kettle has coils A and B. When coil A is switched on, the water boils in 10 minutes, and when coil B is switched on, the water boils in 20 minutes. Calculate the time taken by the water to boil if the coils connected in (a) series and in (b) parallel are switched on.

SOLUTION:

Let R_1 and R_2 be the resistances of the coils A and B respectively, and t_1 and t_2 the time-intervals taken by the water to boil when A and B are switched on turn by turn. If W be the heat energy required to boil the water, then

$$W = \frac{V^2 t_1}{R_1} = \frac{V^2 t_2}{R_2}$$

where V is supply voltage. This gives $\dfrac{R_2}{R_1} = \dfrac{t_2}{t_1}$ .... (1)

Here $t_1 = 10$ min and $t_2 = 20$ min. $\therefore$ $\dfrac{R_2}{R_1} = \dfrac{20}{10} = 2$

or $R_2 = 2R_1$

(a) When the coils are connected in series, the equivalent resistance is

$R = R_1 + R_2 = R_1 + 2R_1 = 3R_1$.

If t be the time taken by the water to boil, then from eq. (1), we have

$$\frac{R}{R_1} = \frac{t}{t_1}\ ;\ t = 3t_1 = 30 \text{ min.} \qquad [\because R/R_1 = 3]$$

(b) When the coils are connected in parallel, the equivalent resistance is $R' = \dfrac{R_1 R_2}{R_1 + R_2} = \dfrac{R_1(2R_1)}{R_1 + 2R_1} = \dfrac{2}{3}R_1$

If t' be the time taken by the water to boil, then from eq. (1) , we have

$$\frac{R}{R_1'} = \frac{t'}{t_1} \quad \text{or} \quad t' = \frac{2}{3}t_1 = \frac{20}{3}\text{ min} \qquad [\because R'/R_1 = 2/3]$$

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ILLUSTRATION 5.14

Two bulbs A and B are rated 100W, 120V and 10W, 120V respectively. They are connected across a 120V source in series. Calculate the current through each bulb. Which bulb will consume more energy ?

SOLUTION :

Resistance of bulb A (rating 100W, 120V) is $R_1 = \frac{V^2}{P_1} = \frac{(120)^2}{100} = 144\ \Omega$

Resistance of bulb B (rating 10W, 120V) is $R_2 = \frac{V^2}{P_2} = \frac{(120)^2}{10} = 1440\ \Omega$

When they are connected in series,
Total resistance, $R = R_1 + R_2 = 144 + 1440 = 1584\Omega$

Current in the circuit $I = \frac{V}{R} = \frac{120}{1584} = 0.076A$

Same current passes through each bulb.
Power consumed in the bulb A is $P_1 = I^2R_1$.
Power consumed in the bulb B is $P_2 = I^2R_2$.
Since, $R_1 < R_2$ $\therefore\ P_1 < P_2$.
Hence, the bulb B (rated 10W, 120V) consumes more energy than the bulb A (rated 100W, 120V) when they are connected in series.

ILLUSTRATION 5.15

There are 5 rooms in a house. Each room has a 100W bulb and a 40W tube light. If every day the bulb is used for 1 hour and tube light is used for 5 hours in each room then what will be the cost of total electric energy consumed in 30 days when 1 unit of electric energy costs ₹ 2.5.

SOLUTION :

Energy used every day in 5 bulbs = 5 × 100 × 1 Wh = 500 Wh
Energy used everyday in 5 tube lights = 5 × 40 × 5 Wh = 1000 Wh
Total energy used everyday by bulb and tube light = (500 + 1000) Wh = 1500 Wh

Total energy used in 30 day = 1500 × 30 Wh = 45000 Wh = $\frac{45000}{1000}$ KWh = 45 KWh (unit)

Cost of the total energy used = 45 × 2.50 ₹ = ₹ 112.50

ILLUSTRATION 5.16

Compute the heat generated while transferring 96000 coulomb of charge in one hour through a potential difference of 50 V.

SOLUTION :

Here, $Q = 96{,}000\ C, t = 1$ hour $= 60 \times 60$s, V = 50 V

Current, $I = \frac{Q}{t} = \frac{96000}{60 \times 60} = \frac{80}{3}A$

Resistance, $R = \frac{V}{I} = \frac{50 \times 3}{80} = \frac{15}{8}\Omega$

Heat produced, $H = I^2Rt = \frac{80}{3} \times \frac{80}{3} \times \frac{15}{8} \times 60 \times 60 = 4800000\text{ J} = 4800\text{ kJ}$

ILLUSTRATION 5.17

When a 12 V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit. Find the value of the resistance of the resistor.

SOLUTION :

Potential difference, V = 12V
Current, $I = 2.5\text{ mA} = 2.5 \times 10^{-3}$ A

We know that, $V = IR$; $R = \frac{V}{I} = \frac{12}{2.5 \times 10^{-3}} = 4.8 \times 10^3\Omega = 4.8\ k\Omega$

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ILLUSTRATION 5.18

Two lamps, one rated 100 W at 220 V, and the other 60 W at 220 V, are connected in parallel to electric mains supply. What current is drawn from the line if the supply voltage is 220 V?

SOLUTION:

We know that, $P = \frac{V^2}{R}$ $\therefore$ $R = \frac{V^2}{P}$

Resistance of 1st lamp, $R_1 = \frac{V^2}{P} = \frac{220 \times 220}{100} = 484\ \Omega$

Resistance of 2nd lamp, $R_2 = \frac{220 \times 220}{60} = \frac{2420}{3}\ \Omega$

Since, two lamps are connected in parallel, so its equivalent resistance is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{484} + \frac{3}{2420} = \frac{5+3}{2420} = \frac{8}{2420} \Rightarrow R = \frac{2420}{8}\ \Omega$$

Current drawn from the line, $I = \frac{V}{R} = \frac{220 \times 8}{2420} = 0.73\ A$

ILLUSTRATION 5.19

A current of 0.5 A is passing through a $CuSO_4$ solution. How many Cu^{++} ions will be deposited on cathode in 10 second?

SOLUTION:

If n is number of copper ions then $q = n \times 2e$

$q = It$ or $n \times 2e = It$ so $n = \frac{It}{2e} = \frac{0.5 \times 10}{2 \times 1.6 \times 10^{-19}} = 1.5625 \times 10^{19}$.

ILLUSTRATION 5.20

Calculate the current flowing through a nichrome wire, immersed in 100g of oil at 20°C, such that final temperature of oil rises to 80°C in five minutes, when the supply of emf is 10V. [Sp. heat capacity of oil is $0.85\ Jg^{-1}{}^{\circ}C^{-1}$]

SOLUTION:

$I = ?$, p.d. $= 10V$, $t = 5\ min = 300s$

$m = 100\ g$, S.H.C. $= 0.85\ Jg^{-1}{}^{\circ}C^{-1}$, $\theta_R = (80 - 20) = 60^{\circ}C$

Energy produced in wire $= I \times V \times t = I \times 10 \times 300\ Vs$

Energy absorbed by oil $= mc\theta_R = 100 \times 0.85 \times 60\ J$

$\therefore$ By the law of conservation of energy $I \times 10 \times 300 = 100 \times 0.85 \times 60 \Rightarrow I = \frac{100 \times 0.85 \times 60}{10 \times 300} = 1.7\ A$

ILLUSTRATION 5.21

Two coils of resistance 3Ω and 6Ω are connected across battery of emf 12V. Find the electrical energy consumed in 1 minute in each resistance when they are connected in series. Draw the circuit diagram.

SOLUTION:

The circuit is shown in figure.

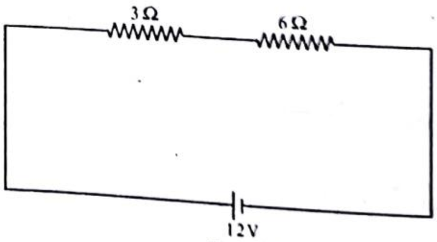

Fig. 5.14

Total resistance of the circuit $R = 3 + 6 = 9\Omega$.

Current in the circuit $I = \frac{V}{R} = \frac{12}{9} = \frac{4}{3} A$

Since the resistance are in series, same current flows in each resistance.

Electrical energy spent in $R_1 = I^2 R_1 t = \left(\frac{4}{3}\right)^2 \times 3 \times 60 = 320\ J$

Electrical energy spent in $R_2 = I2R_2 t = \left(\frac{4}{3}\right)^2 \times 6 \times 60 = 640\ J$

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MISCELLANEOUS SOLVED EXAMPLES

1. A bulb has voltage rating of 220 V and power rating of 40 W. How can this bulb be made to glow with normal brightness if a voltage source of e.m.f. 330 V is available?

Sol. Here $V = 220\ V$; $P = 40\ W$

Resistance of the bulb, $R = \frac{V^2}{P} = \frac{(220)^2}{40} = 1210\Omega$

Current in the circuit, $I = \frac{330}{1210+S}$

Potential difference across the bulb,

$$IR = \left(\frac{330}{1210+S}\right)1210$$

As per question, $220 = \frac{330 \times 1210}{1210+S}$

On solving, we get $S = 605\ \Omega$

2. If two bulbs of wattage 25 and 30 W, each rated at 220 volts are connected in series with a 440 volt supply, which bulb will fuse?

Sol. Resistance of 25 W bulb, $R_1 = \frac{(220)^2}{25}\Omega$;

$$\text{Current } I_1 = \frac{25}{220} A$$

Resistance of 30 W bulb, $R_2 = \frac{(220)^2}{30}\Omega$,

$$\text{Current } I_2 = \frac{30}{220} A$$

When bulbs are connected in series, effective resistance is

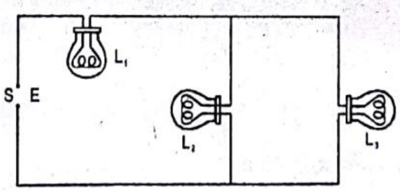
$$R = R_1 + R_2 = (220)^2\left[\frac{1}{25} + \frac{1}{30}\right] = 220 \times 220 \times \frac{11}{150}\Omega$$

When supply voltage is 440 V, then current is

$$I' = \frac{440}{R} = \frac{440 \times 150}{220 \times 220 \times 11} = \frac{27.27}{220} A$$

As $I' > I_1$ but less than I_2, hence the bulb of 25 watt will fuse.

3. Fig. shows three similar lamps L_1, L_2 and L_3 connected across a power supply.



If the lamp L_3 fuse, how will the light emitted by L_1 and L_2 change?

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Sol. Let R be the resistance of each lamp. If E be the applied e.m.f., then the current in the circuit, I_1, is given by

$$I_1 = \frac{E}{R+(R/2)} = \frac{2E}{3R}$$

Current flowing through L_2 or $L_3 = \frac{1}{2}\left[\frac{2E}{3R}\right] = \frac{E}{3R}$

When L_3 is fused, the whole current flows through L_1 and L_2.

Thus, $\quad I_2 = \frac{E}{R+R} = \frac{E}{2R}$

So, current through L_1 decreases and through L_2 increases.

4. 1 kW heat is to be used with 220 V d.c. supply. (i) What is the current in the heater? (ii) What is its resistance? (iii) What is the power dissipated in the heater (iv) How much heat in calories is produced per second? (v) How many grams of water at 100°C will be converted per minute into steam at 100°C with the heater? Assume that heat loses due to radiation are negligible. Latent heat of steam = 540 cal g^{-1}.

Sol. (i) $I = P/V = 1000/220 = 4.5\,A$

(ii) $R = V^2/P = (220)^2/1000 = 48.4\,\Omega$

(iii) $P = 1\,kW = 1000\,W$

(iv) $H = 1000/4.2 = 238.1\,cal\,s^{-1}$

(v) Let m gram water be converted into steam at 100° C in one minute. Then

$$m \times 540 = \frac{1000 \times 60}{4.2} \text{ or } m = \frac{1000 \times 60}{4.2 \times 540} = 26.46\,g.$$

5. A fuse wire with a circular cross section and having diameter of 0.4 mm blows with a current of 3 amp. The value of the current for which another fuse wire made of the same material but having circular cross-section with diameter of 0.06 mm will blow is

Sol. For a fuse wire $I^2 \propto r^3$

$$\therefore \quad \frac{I_1^2}{I_2^2} = \frac{r_1^3}{r_2^3}$$

where $r_1 = \frac{0.04}{2} = 0.02$ cm and $r_2 = \frac{0.06}{2} = 0.03$ cm.

$$\therefore \quad \frac{(3)^2}{I_2^2} = \left(\frac{0.02}{0.03}\right)^3 = \left(\frac{2}{3}\right)^3$$

or $\quad I_2^2 = (3)^2\left(\frac{3}{2}\right)^3 \quad$ or $\quad I_2 = 3 \times \left(\frac{3}{2}\right)^{3/2}$

6. An accumulator is connected first to an external resistance R_1 and then to another external resistance R_2 for the same time. At what value of the internal resistance of the accumulator will the amount of heat dissipated in the external resistances be the same in the two cases ?

Sol. When an accumulator of emf E and internal resistance r is connected across a load resistance R, the heat dissipated in the external circuit $\quad H = I^2Rt = \frac{E^2Rt}{(R+r)^2} \quad \left[\text{as } I = \frac{E}{(R+r)}\right]$

According to given problem :

$$\frac{E^2R_1t}{(R_1+r)^2} = \frac{E^2R_2t}{(R_2+r)^2} \text{ i.e., } (R_2 - R_1)(r^2 - R_1R_2) = 0$$

And as $R_2 \neq R_1$ (given) $\quad r^2 - R_1R_2 = 0$

7. How will you connect 24 cells each of internal resistance 1Ω so as to get maximum power output across a load of 10Ω ?

Sol. For maximum power output $\frac{R}{n}=\frac{r}{m}$

and $n \times m = p = 24$

So $R=\frac{n}{m}r=\frac{pr}{m^2}$

or $m^2=\frac{pr}{R}=\frac{24\times 1}{10}$ or $m=\sqrt{2.4}=1.56$

(a) If $m=1$ then $n=\frac{p}{m}=24$

so $$P_1=\frac{RE^2}{\left(\frac{R}{n}+\frac{r}{m}\right)^2}=\frac{10E^2}{\left(\frac{10}{24}+1\right)^2}=5E^2$$

(b) If m = 2 then $n=\frac{p}{m}=\frac{24}{2}=12$

so $$P_2=\frac{10E^2}{\left(\frac{10}{12}+\frac{1}{2}\right)^2}=5.6E^2$$

So to get maximum output power cells must be arranged in two rows having 12 cells in each row.

8. If electrochemical equivalent of hydrogen is Z_H kg/coul-equivalent and chemical equivalent of copper is W, then the electrochemical equivalent of copper is

Sol. $\frac{Z_{Cu}}{Z_H}=\frac{W}{W_H}$

We know that, $W_H=1$

$\therefore \quad Z_{Cu}=W.Z_H$

9. Find the mass of silver liberated in a silver voltameter carrying a current of 1.5A, during 15 minutes. The electro chemical equivalent of silver is 1.12×10^{-6} kg/C.

Sol. Here, $m=?, i=1.5\,A, Z=1.12\times 10^{-6}$ kg/c

and $t=15\times 30s$

Using $m=Zit$ yields

mass of silver liberated is

$$m=\left(1.12\times 10^{-6}\frac{\text{kg}}{c}\right)\left(\frac{1.5c}{s}\right)(450s)=7.6\times 10^{-4}\,\text{kg}=0.76\,\text{g}$$

10. In a water voltameter, the act of passing a certain amount of current for a certain time produces of 1.2g of H_2 at STP. Find the amount of O_2 liberated during that period.

Sol. Since the same current flows through both the electrodes of a water voltameter, so the amount of oxygen and hydrogen liberated (for the same charge) will be in direct proportional to their respective equivalent weights by Faraday's second law of electrolysis,

i.e., $\frac{m_0}{m_H}=\frac{8}{1}$ or $m_0=\left(\frac{8}{1}\right)m_H=8\times 1.2g=9.6g$

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1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. Kilowatt is the unit of electrical .... but kilowatt-hour is the unit of electrical ....
2. Energy spent in kilowatt-hour

$$= \frac{\text{volt} \times \ldots\ldots\ldots \times \ldots\ldots\ldots}{1000}$$

3. A fuse is a short piece of wire of high .... and low ....
4. Fuse wire has a .... melting point and is made of an alloy of ....and .... If the current in a circuit rises too high, the fuse wire ....
5. A fuse is connected in .... to the .... wire.
6. Electric energy is produced by the .... of charges.
7. Energy converted per unit charge is measured with an instrument called a (*n*)....................
8. The electrical energy dissipated in a resistor is given by W = ...
9. The unit of power is ....
10. One watt of power is consumed when 1 A of current flows at a potential difference of ....
11. 1 kW h = ...
12. The alloy which is used for making the filament of bulbs is ....
13. Power transmission is carried out at high......................... and low ....
14. Rate at which electric work is done is called ....
15. The process of depositing a thin layer of desired metal over another metal by passing an electric current through some electrolyte is called ....
16. For a given cell, its terminal voltage depends on .... and ....

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. The filament resistance of glowing bulb is greater, to its resistance when it is not glowing ?
2. The commercial unit of electrical energy is kilowatt-hour (kWh).
3. Pure tungsten has high resistivity and a high melting point (nearly 3000°C).
4. When a metallic conductor is heated the atoms in the metal vibrate with greater amplitude and frequency.
5. The used up chemicals in a dry cell can be reobtained by charging it.
6. In an electrolyte, the movement of ions is responsible for electric current.
7. Electrotyping is an application of electrolysis.
8. One kilowatt is equal to 10 horse power.
9. The mass of the element deposited at the electrode when one coulomb of charge is passed through the electrolyte is called electrochemical equivalent of the element.
10. The terminal voltage of a cell in open circuit condition is less than its emf
11. Fuse should be connected to phase wire of the circuit.
12. Fuse is a thin wire which melts and breaks the electric circuit due to only high voltage.
13 The difference between EMF (E) of the cell and terminal voltage (V) of a cell is called lost voltage.
14 The filament of bulb offers high resistance to electric current.

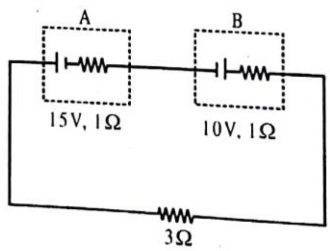
Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

1. Column II gives name of material use for device given in column I

Column I	Column II
(A) Resistance of resistance box	(p) tungsten
(B) Fuse wire	(q) maganin
(C) Bulb	(r) tin-lead alloy
(D) Insulator	(s) glass

2. For the circuit shown in the adjoining figure, match the entries of column I with the entries of column II.



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Column I	Column II
(A) Potential difference across battery A	(p) A
(B) Potential difference across battery B	(q) B
(C) Power is supplied by battery	(r) 14V
(D) Power is consumed by battery	(s) None

3. For a potentiometer circuit match the column

Column I	Column II
(A) Sensitivity	(p) increases with length of wire
(B) Accuracy	(q) decreases with length of wire
(C) Range	(r) increases with emf of primary cell
(D) Potential gradient	(s) maximum if internal resistance & rheostat resistance is zero.

VSAQ Very Short Answer Questions :

DIRECTIONS : *Give answer in one word or one sentence.*

1. What is a fuse and specify its uses?
2. Find the total internal resistance of the cells when they are connected in
   (a) series and (b) parallel connections
3. What is the use of kilowatt-hour meter?
4. What is the value of mechanical equivalent of heat (J)?
5. Define terminal voltage, internal resistance and lost voltage.
6. What is watt-hour?
7. Define electric energy or work.
8. Define electric power and give its units in S.I.
9. What is electro plating?
10. How is the electric current passing though a metallic wire produces heat ?
11. What is the operating resistance of a 100-watt household light bulb ? The operating line voltage of household electricity is 120V.
12. Why are coils of electric toasters and electric irons made of an alloy rather than a pure metal ?
13. Why does the cord of an electric heater not glow while the heating element does ?
14. How does the amount of current in a household circuit differ from the amount of current in a reading lamp?
15. Would you expect to find DC or AC in the filament of a light bulb in your home? How about in the headlight of an automobile?
16. A 220 volt 100 watts bulb is connected to 110 volts source, calculate the power consumed by the bulb.
17. A current of 0.5 A is passing through a $CuSO_4$ solution. How many Cu^{++} ions will be deposited on cathode in 10 second?
18. An electric bulb is connected to a 220V generator. The current is 0.50V. What is the power of the bulb ?
19. What uses more energy, a 250 W TV set in 1 hr. or a 1200W toaster in 10 minutes ?
20. Name two devices which use the heating effect of current.
21. Why is the filament of an electric bulb not made of carbon?
22. 60W-220V is written on a bulb. What does it mean ?
23. Name the term used to represent the values of the voltage and wattage (power) of an electrical appliance taken together.

SQA Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. Obtain an expression for the (i) electrical energy (ii) electrical power, spent in flow of current through a conductor.
2. A 60W auto lamp allows 5 amps to pass through it. Find
   (i) The p.d. across its terminal.
   (ii) the resistance of the filament of the lamp
   (iii) energy consumed in 2 hours
3. What is the electric power ? Derive a formula for it ?
4. An electric iron consumes energy at a rate of 840W when heating is at the maximum rate and 360W when the heating is at the minimum. The voltage is 220V. What are the current and the resistance in each case?
5. A geyser is rated 1500W, 250V. This geyser is connected to 250V mains. Calculate : (i) the current drawn, (ii) the energy consumed in 50 hours. (iii) the cost of energy consumed at ' 220 per kWh.
6. An electric iron of resistance 20Ω takes a current of 5A. Calculate the heat developed in 30s.
7. Compare the power used in the 2Ω resistor in each of the following circuits :
   (i) a 6V battery in series with 1Ω and 2Ω resistors and (ii) a 4V battery in parallel with 12Ω and 2Ω resistors.
8. An electric heater of resistance 8Ω draws 15A from the service mains 2 hours. Calculate the rate at which heat is developed in the heater.
9. 100J of heat are produced each second in a 4Ω resistance. Find the potential difference across the resistor.
10. In the home electrical energy is converted into other energy forms. What is the energy conversion when
    (a) an electric bell is used ?
    (b) an electric toaster is used ?
    (c) a fluorescent tube is switched on ?
    (d) an electric fan is used ?

11. An immersion heater having 50Ω resistance is connected to 250V mains. Find the time required to heat 2 kg of water from 34°C to 100°C, assuming there is no loss of heat energy (Sp. heat cap. of water = 4×10^3 J/kg°C).
12. Two bulbs are marked 60 W, 220 V and 100 W, 220V. These are connected in parallel to 220 V main. Which one of the two will glow brighter ?
13. A toaster produces more heat than a light bulb when connected in a parallel to the 220 V mains. Which of the has greater resistance?
14. An electric heater is used everyday for 120 minutes. The electricity bill for 30 days is 60 units. Calculate the power of the electric heater.
15. In a household 5 tubelights of 40 W each are used for 5 hours and an electric press of 500 W for 4 hours everyday. Calculate the total electrical energy consumed by the tubelights and press in a month of 30 days.
16. A 100 W electrical bulb is lighted for 2 hours everyday and five 40 W tubes are lighted for 4 hours everyday. Calculate
    (i) The energy consumed for 60 days and
    (ii) Cost of electricity consumed at the rate of '1.50 per kWh.
17. What is meant by rating of electrical appliance?
18. What are the factors on which heat dissipated by a conductor depends?
19. Why is heat produced when a current is passed through a conductor?
20. Define one watt.
21. Why should the melting point of a fuse wire be low?
22. The filament of electric bulb is made of tungsten. Why?

LAQ Long Answer Questions :

DIRECTIONS : *Give answer in four to five sentences.*

1. What are the safety measures to be taken while dealing with household electricity?
2. (i) What do you understand by earthing?
   (ii) What are the advantages of earthing in a household electric circuit?
   (iii) Explain how it is done.
3. Three 250 watt heaters are connected in parallel to a 100 volt supply. Calculate :
   (i) the total current taken from the supply.
   (ii) the resistance of each heater.
   (iii) the energy supplied in kWh to the three heaters in 5 hours.
4. A heating coil is immersed in a calorimeter of heat capacity 50 J°C^{-1} containing 1.0 kg of a liquid of specific heat capacity 450 J kg^{-1} °C^{-1}. The temperature of liquid rises by 10°C when 2.0 A current is passed for 10 minutes. Find (i) the resistance of the coil (ii) the potential difference across the coil. State the assumption used in your calculations.
5. State Joule's law. Explain an experimental method to determine the value of J.
6. Sate Farady's first law and second law of electrolysis and verify it experimentally.
7. Explain the working of the following
   (i) Filament lamp
   (ii) Flourescent lamp
   (iii) Discharge lamp
   (iv) Electric are lamp
   (v) Drycells

2 EXERCISE

MCQ Multiple Choice Questions :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Two electric lamps each of 100 watts 220V are connected in series to a supply of 220 volts. The power consumed would be –
   (a) 100 watts (b) 200 watts
   (c) 25 watts (d) 50 watts
2. An electric bulb is rated 220V and 100W. When it is operated on 110V, the power consumed will be
   (a) 100W (b) 75W
   (c) 50W (d) 25W
3. If it takes 8 minutes to boil a quantity of water electrically, how long will it take to boil the same quantity of water using the same heating coil but with the current doubled
   (a) 32 minutes (b) 16 minutes
   (c) 4 minutes (d) 2 minutes
4. Kilowatt-hour is the unit of
   (a) potential difference (b) electric power
   (c) electrical energy (d) charge
5. An electric bulb is filled with
   (a) hydrogen (b) oxygen and hydrogen
   (c) ammonia (d) nitrogen and argon
6. When current is passed through an electric bulb, its filament glows, but the wire leading current to the bulb does not glow because
   (a) less current flows in the leading wire as compared to that in the filament

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(b) the leading wire has more resistance than the filament
(c) the leading wire has less resistance than the filament
(d) filament has coating of fluorescent material over it

7. From a power station, the power is transmitted at a very high voltage because –
(a) it is generated only at high voltage
(b) it is cheaper to produce electricity at high voltage
(c) electricity at high voltage is less dangerous
(d) there is less loss of energy in transmission at high voltage

8. When a fuse is rated 8A, it means
(a) it will not work if current is less than 8A
(b) it has a resistance of 8 ohm
(c) it will work only if current is 8A
(d) it will burn if current exceeds 8A

9. Fuse wire is made of
(a) platinum (b) copper
(c) aluminium (d) alloy in tin and lead

10. Which is not a device based on the heating effect of electricity
(a) heater (b) toaster
(c) refrigerator (d) press

11. Which of the following terms does not represent electrical power in a circuit?
(a) I^2R (b) IR^2
(c) VI (d) V^2/R

12. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combinations would be
(a) 1:2 (b) 2:1
(c) 1:4 (d) 4:1

13. On which one of the following the emf of a cell does not depend
(a) The nature of the metal of electrodes
(b) The size of the plates
(c) Nature of the electrolyte
(d) The nature of electrodes

14. The primary cell which is used in daily life is –
(a) Leclanche cell (b) Dry cell
(c) Daniel cell (d) Simple voltaic cell

15. Which one of the following primary cells has emf 1.08 volts and which remains fairly constant?
(a) Daniel cell (b) Simple voltaic cell
(c) Leclanche cell (d) Dry cell

16. Primary cell are connected in parallel to
(a) Increase voltage
(b) decrease capacity
(c) decrease internal resistance
(d) make electric current constant

17. In a closed circuit drawing current from cell, the emf of a cell is always
(a) Less than potential difference
(b) More than potential difference
(c) Half of the potential difference
(d) Double of the potential difference

18. The filament of an electric bulb is of tungsten because
(a) Its resistance is negligible
(b) It is cheaper
(c) Its melting point is high
(d) Filament is easily made

19. When the current passes through the filament, it gets heated to incandescence and give light while the connecting wires are not heated because
(a) The connecting wires are good conductor of heat while the filament is bad conductor
(b) The connecting wires are of low resistance while the filament is of high resistance
(c) The density of connecting wires is less than that of the filament
(d) The connecting wires are bad conductor of heat while the filament is good conductor

20. The bulbs which emit a bluish light, are
(a) Filled with argon
(b) Filled with nitrogen
(c) vacuum bulbs
(d) coated from inside with a light blue colour

21. Which one of the following heater element is used in electric press
(a) copper wire (b) nichrome wire
(c) lead wire (d) iron wire

22. If 10 cells each of 1.4 volts are connected in parallel, their equivalent potential difference will be
(a) 1.4 volts (b) 0.14 volts
(c) 14 volts (d) 10/1.4 volts

23. What should be the characteristic of fuse wire?
(a) High melting point, high specific resistance
(b) Low melting point, low specific resistance
(c) High melting point, low specific resistance
(d) Low melting point, high specific resistance

24. The heating element of an electric heater should be made with a material, which should have
(a) high specific resistance and high melting point
(b) high specific resistance and low melting point
(c) low specific resistance and low melting point
(d) low specific resistance and high melting point

25. Resistance of conductor is doubled keeping the potential difference across it constant. The rate of generation of heat will
(a) become one fourth (b) be halved
(c) be doubled (d) become four times

26. A current I passes through a wire of length l, radius r and resistivity r. The rate of heat generated is
(a) $\frac{I^2\rho\ell}{r}$ (b) $\frac{I^2\rho\ell}{\pi r^2}$
(c) $\frac{I^2\rho\ell}{\pi r}$ (d) none of these

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27. The resistance R_1 and R_2 are joined in parallel and a current is passed so that the amount of heat liberated is H_1 and H_2 respectively. The ratio H_1/H_2 has the value
(a) R_2/R_1 (b) R_1/R_2
(c) R_1^2/R_2^2 (d) R_2^2/R_1^2

28. Two electric bulbs rated P_1 watt V volts and P_2 watt V volts are connected in parallel and applied across V volts. The total power (in watts) will be
(a) P_1+P_2 (b) $\sqrt{P_1P_2}$
(c) $\frac{P_1P_2}{P_1+P_2}$ (d) $\frac{P_1+P_2}{P_1P_2}$

29. First electro chemical cell was designed by
(a) Leclanche (b) Faraday
(c) Galvanic
(d) Some one other than those mentioned above

30. The electric cell is a device to obtain
(a) electric charge (b) electric force
(c) electrons
(d) electric energy from chemical energy

31. In which of the following cells polarisation is the major defect?
(a) Voltaic cell (b) Daniel cell
(c) Leclanche cell (d) Fuse cell

32. Which of the following is NOT the name of a secondary cell?
(a) Storage cell (b) Fuel cell
(c) Alkali cell (d) Acid cell

33. The current capacity of the charged secondary cell does not depend on
(a) rate of charging
(b) rate of discharging
(c) temperature
(d) amount of active material

34. Which of the following is not the storage cell?
(a) Acid cell (b) NIFE cell
(c) Edison cell (d) Dry cell

35. In charging a battery of motor car, the following effect of electric current is used
(a) magnetic (b) heating
(c) chemical (d) induction

36. Same current is being passed through a copper voltameter and silver voltameter. The rate of increase in weight of the cathodes in the two voltameters will be proportional to
(a) relative densities (b) atomic masses
(c) atomic numbers (d) none of the above

37. If E be chemical equivalent of an element and Z is its electrochemical equivalent, then E/Z is measured in
(a) farad (b) newton
(c) coulomb (d) faraday

38. A silver and a zinc voltameter are connected in series and a current I is passed through them for a time t, liberating W grams of zinc. The weight of silver deposited is nearly
(a) 1.7 W grams (b) 2.4 W grams
(c) 3.5 W grams (d) 1.2 W grams

39. What determines the e.m.f. between the two metals placed in an electrolyte?
(a) relative position of metals in the electro chemical series
(b) distance between them
(c) strength of electrolyte
(d) nature of electrolyte

40. For electroplating a spoon, it is placed in the voltameter at
(a) the position of anode
(b) the position of cathode
(c) exactly in the middle of anode and cathode
(d) anywhere in the electrolyte

41. Electroplating does not help in
(a) fine finish to the surface
(b) shining appearance
(c) metals to become hard
(d) protect metals against corrosion

42. Faraday's laws are consequence of conservation of
(a) energy
(b) energy and magnetic field
(c) charge
(d) magnetic field

43. According to Faraday's law of electrolysis, the amount of decomposition is proportional to
(a) 1/time for which current passes
(b) electrochemical equivalent of the substance
(c) 1/current
(d) 1/electrochemical equivalent

44. The current inside a copper voltameter
(a) is half the outside value
(b) is the same as the outside value
(c) is twice the outside value
(d) depends on the concentration of $CuSO_4$.

45. In electrolysis, the amount of mass deposited or liberated at an electrode is directly proportional to
(a) amount of charge
(b) square of current
(c) concentration of electrolyte
(d) square of electric charge

46. Of the following, the one that does not make use of chemical effect of electric current is
(a) electroplating
(b) electrotyping
(c) thermoelectric refrigerator
(d) voltaic cells

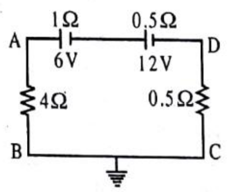
MTQC More than One Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. A constant voltage is applied between the two ends of a uniform metallic wire. If both the length and radius of wire are doubled, then:
(a) the heat developed in the wire will be doubled
(b) the electric field in the wire will be doubled
(c) the heat developed will remain the same
(d) the electric field in the wire will be halved

2. The emf of a cell is:
(a) the potential difference across its terminals
(b) the potential difference across its terminals when no current is passing through it
(c) the heat produced when the cell is connected across a one ohm resistance
(d) the total work done per coulomb of electricity taken in a circuit in which the cell is connected

3. In the circuit shown in the figure:

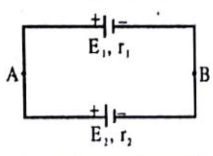


(a) the voltage at the point A is 6 V
(b) the voltage at the point D is – 0.5 V
(c) if a voltmeter is connected across the 6V battery, it will read 7V
(d) if the voltmeter is connected across a 6V battery, it will read 5 V

4. When the terminals of a cell of e.m.f. 1.5 V are connected to an ammeter of resistance 4Ω, the ammeter reads 0.30 amp. Which of the following statements is/are correct?
(a) The cell is non-ideal
(b) If a 4Ω resistor is also connected across terminals of the cell, the ammeter will read 0.50 amp.
(c) If a 4Ω resistor is also connected across the terminals of the cell, one-third of the electrical powe generated will dissipate as heat within the cell.
(d) If a voltmeter of resistance 4Ω is used to measure potential difference between terminals of the cell, it will read 1.2V.

5. Which of the following statements is/are correct?
(a) Potential difference between terminals of a non-ideal battery can never be greater than its e.m.f.
(b) If a non-ideal battery is short circuited by a wire, heat generater in the wire is less than electric energy developed in the battery.
(c) e.m.f. of an ideal battery is first measured by a potentiometer and then by a voltmeter. Both the measurements are equally correct.
(d) Ncne of the above.

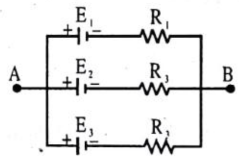
6. Two cells of unequal e.m.fs. E_1 and E_2 and internal resistances r_1 and r_2 are joined as shown. V_A and V_B are the potentials at A and B respectively:



(a) one cell will continuously supply energy to the other
(b) the potential difference across both the cells will be equal
(c) the potential difference across one cell will be greater than its e.m.f.
(d) $V_A - V_B = \dfrac{(E_1 r_2 + E_2 r_1)}{(r_1 + r_2)}$

7. Which of the following statement(s) is/are correct?
(a) If n identical cells are connected in series and then the battery thus formed is short circuited by a conduction wire, current through the wire will be independent of n.
(b) If n identical cells are connected in parallel and then the battery thus formed is short circuited by conducting wire, current through the wire will be directly proportional to n.
(c) If n identical cell are connected in parallel and then the battery thus formed is short circuited by a wire having a constant resistance, current through the wire will increase as n increases.
(d) None of the above.

8. For the battery shown in the figure:



(a) equivalent internal resistance R is given by:
$$\frac{1}{R} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$
(b) if $E_3 = \dfrac{(E_1 R_2 + E_2 R_1)}{(R_1 + R_2)}$, equivalent e.m.f. of the battery will be equal to E_3
(c) equivalent e.m.f. of the battery is equal to $E = (E_1 + E_2 + E_3)/3$
(d) equivalent e.m.f. of the battery not only depends upon values of E_1, E_2 and E_3 but depends upon values of R_1, R_2 and R_3 also

9. A cell of e.m.f. 5V and internal resistance 1Ω will give maximum power output to:
(a) a single resistor of 1Ω
(b) two 1Ω resistors connected in series
(c) two 1Ω resistors connected in parallel
(d) two 2 Ω resistors connected in parallel

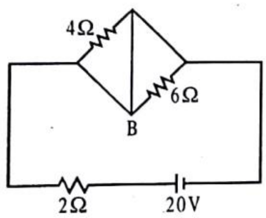
10. Two heaters designed for the same voltage V have different power ratings. When connected individually across a source of voltage V, they produce H amount of heat each in times t_1 and t_2 respectively. When used together across the same source, they produce H amount of heat in time t:
(a) if they are in series, $t = t_1 + t_2$
(b) if they are in series, $t = 2(t_1 + t_2)$
(c) if they are in parallel, $t = \dfrac{t_1 t_2}{(t_1 + t_2)}$
(d) if they are in parallel, $t = \dfrac{t_1 t_2}{2(t_1 + t_2)}$

11. In a household electric circuit:
(a) all electric appliances drawing power are joined in parallel
(b) a switch may be either in series or in parallel with the appliance which it controls
(c) if a switch is in parallel with an appliance, it will draw power when the switch in the off position (open)
(d) if switch is in parallel with an appliance, the fuse will blow (burn out) when the switch is put on (closed)

12. A cell drives a current through a circuit. The e.m.f. of the cell is equal to the work done in moving unit charge:
(a) from the positive to negative plate of the cell
(b) from the positive plate back to the positive plate
(c) from the negative plate back to the negative plate
(d) from any point in the circuit back to the same point

13. A cell of e.m.f. E and internal resistance r drives a current I through an external resistance R:
(a) the cell supplies EI power
(b) heat is produced in R at the rate EI
(c) heat is produced in R at the rate $EI\left(\frac{R}{R+r}\right)$
(d) heat is produced in the cell at the rate $EI\left(\frac{r}{R+r}\right)$

14. In the circuit shown in the fiugre:



(a) power supplied by the battery is 200 watt
(b) current flowing in the circuit is 5A
(c) potential difference across 4Ω resistance is equal to the potential difference across 6Ω resistance
(d) current in wire AB is zero

FIP Fill in the Passage :

DIRECTIONS : *Complete the following passage(s) with an appropriate word/term to be filled in the blank spaces.*

I

melt	fuse	live wire	exceeds
zero	eliminated		

Different electric circuits can withstand certain maximum amount of current without getting heated up and damaging themselves. For example, for a lighting circuit this limit is 5 A and for a heating circuit, it is 15 A. If current approaches this value, fuse wire will ....1............. . Thus, the current ratings of ....2............. should be less than the maximum current that can safely flow through the circuit.
Fuse should be connected in ....3............... of circuit. If it is connected to neutral wire, the fuse will melt when current ....4............. its rating, but the appliance will still be connected to high potential of supply through live wire. If a person touches the appliance, his body provides a path for current to flow to earth which is at ....5............. potential. Thus, person may get severe shock which may prove fatal. Hence, fuse is connected to live wire so that if it melts, the appliance is no longer connected to the high potential of the supply and possibility of electric shock is ....6.............

II

insulation	zero	earth	body
conducting	touched		conducting

When the ....1............. of live wire in a circuit inside a electric appliance melts due to some reasons, the live wire may touch the metal casing of the appliance. Thus, metal casing is connected to high potential. This metal casing of appliances such as mixer, fan, refrigerator, toaster etc., is continuously ....2............. by us by our bare hands. Hence, we may get a severe shock as current will flow through our ....3............. to ....4............. which is considered as ....5............. potential. To prevent this, metal casings of all appliances are connected to earth by a ....6............. wire. This is called earthing.
Thus, ...7............. involves connecting metal body of electric appliance to thick copper wire which is connected to a copper plate buried deep in the earth. The copper plate is surrounded by a mixuture of charcoal and common salt.

III

conductor	free electrons	higher potential
lower potential	colliding	vibrate
temperature	kinetic energy	insulator

When a potential difference is applied between the ends of a ....1............., current begins to flow through it. The current flows as conductor contains large number of ....2............. which begin to drift from the end at ....3.............to the end at ....4............. . In the process they constantly keep on ....5............. with atoms of conductor. The atoms gain energy and beging to ....6............. more vigorously about their mean position. The average ....7............. of atoms of conductor increases. The results in a rise in the ....8............. of the conductor and we say that the conductor has been heated. Thus, flow of current has a heating effect on the conductor.

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Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

Passage-I

Two tungsten lamps with resistances R_1 and R_2 respectively at full incandescence are connected first in parallel and then in series, in a lighting circuit of negaligible internal resistance. It is given that: $R_1 > R_2$.

1. Which lamp will glow more brightly when they are connected in parallel?
(a) Bulb having lower resistance
(b) Bulb having higher resistance
(c) Both the bulbs
(d) None of the two bulbs

2. If the lamp of resistance R_1 now burns out, how will the illumination produced change?
(a) Net illumination will increase
(b) Net illumination will decrease
(c) Net illumination will remain same
(d) Net illumination will reduced to zero

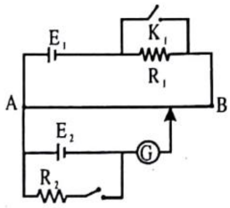
3. Which lamp will glow more brightly when they are connected in series?
(a) Bulb having lower resistance
(b) Bulb having higher resistance
(c) Both the bulbs
(d) None of the two bulbs

4. If the lampe of resistance R_2 now burns out and the lamp of resistance R_1 alone is plugged in, will the illumination increase or decrease?
(a) Illumination will remain same
(b) Illumination will increase
(c) Illumination will increase
(d) Illumination will decrease

5. Would physically bending a supply wire cause any change in the illumination?
(a) Illumination will remain same
(b) Illumination will increase
(c) Illumination will decrease
(d) It is not possible to predict from the given data

Passage-II

Figure shows the circuit of a potentiometer. The length of the potentiometer wire AB is 50 cm. The emf of the battery resistances R_1 and R_2 are 15 ohm and 5 ohm respectively. When both the keys are open, the null point is obtained at a distance of 31.25 cm from end A but when both the keys are closed, the balance length reduces to 5 cm only. Given $R_{AB} = 10\Omega$.



6. The emf of the cell E_2 is:
(a) 1 volt (b) 2 volt
(c) 3 volt (d) 4 volt

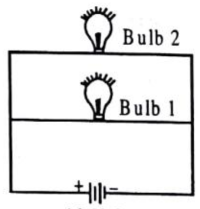
7. The internal resistance of the cell E_2 is:
(a) $4.5\,\Omega$ (b) $5.5\,\Omega$
(c) $6.5\,\Omega$ (d) 7.5Ω

8. The balance length when key K_2 is open and K_1 is closed, is given by:
(a) 10.5 cm (b) 11.5 cm
(c) 12.5 cm (d) 13.5 cm

9. The blance length when key K_1 is open and K_2 is closed, is given by:
(a) 10.5 cm (b) 11.5 cm
(c) 12.5 cm (d) 13.5 cm

Passage-III

A 12 volt battery is connected to two light bulbs, as shown in figure. Light bulb 1 has resistance 3 ohm, while light bulb 2 has resistance 6 ohm. The battery has essentially no internal resistance and all the wires are essentially resistanceless too. When a light bulb is unscrewed, no current flows through that branch of the circuit. For instance, if light bulb 2 is unscrewed, current flows only around the lower loop of the circuit, which consists of the battery and light bulb 1. When two resistances are joined in series, their equivalent resistances $R_{eq} = R_1 + R_2$ but when two resistances are wired in parallel, their net resistance is given by:



$$\frac{1}{R_{eq.}} = \frac{1}{R_1} + \frac{1}{R_2}$$

10. When bulb 1 is screwed in, but bulb 2 is unscrewed, the power generated in bulb 1 is:
(a) 4 watt (b) 12 watt
(c) 36 watt (d) 48 watt

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11. Which of the following statements is false?
(a) Some of the energy produced by the light bulb takes the form of heat
(b) The battery is the source of all the electrons flowing around the circuit
(c) The current entering the light bulb equals the current leaving the light bulb
(d) The potential in the wire to the left of the light bulb differs from the potential in the wire to the right of that bulb

12. Bulb 2 is now screwed in, as a result, bulb 1
(a) turns off
(b) becomes dimmer
(c) stays about the same brightness
(d) becomes brighter

13. When both light bulbs are screwed in, the current through the battery is
(a) 1.2 ampere (b) 2 ampere
(c) 4 ampere (d) 6 ampere

14. With only light bulb 1 screwed in, a never quit 12 volt battery goes dead in 24 days. With both light bulbs screwed in a never quit 12 volt battery goes dead in:
(a) 12 days (b) 14 days
(c) 16 days (d) 18 days

A&R *Assertion & Reason :*

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect**.
(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** When current through a bulb decreases by 0.5%, the glow of bulb decreases by 1%.
Reason : Glow (Power) which is directly proportional to square of current.

2. **Assertion :** Long distance power transmission is done at high voltage.
Reason : At high voltage supply power losses are less.

3. **Assertion :** Resistance of 50W bulb is greater than that of 100 W.
Reason : Resistance of bulb is inversely proportional to rated power.

4. **Assertion :** 40 W tube light give more light in comparison to 40 w bulb.
Reason : Light produced is same from same power.

5. **Assertion :** A resistor of resistance R is connected to an ideal battery. If the value of R is decreased, the power dissipated in the circuit will increase.
Reason : The power dissipated in the circuit is directly proportional to the resistance of the circuit.

6. **Assertion :** A voltmeter and ammeter can be used together to measure resistance and power.
Reason : Resistance and power both are proportional to voltage and current.

7. **Assertion :** A torch bulb give light if operated on AC of same voltage and current as DC.
Reason : Heating effect is common to both AC and DC.

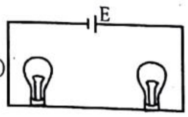
8. **Assertion :** A tube light emits white light.
Reason : Emission of light in a tube takes place at a very high temperature.

MMQ *Multiple Matching Questions :*

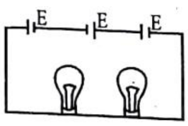
DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given Assertionn Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1 For the circuit shown in the adjoining figure, match the entries of column I with the entries of column II.

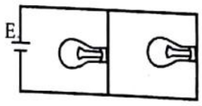
Column I **Column II**

(a) 

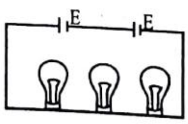
(p) Current drawn from the battery is maximum

(b) 

(q) Current drawn from the battery is the least

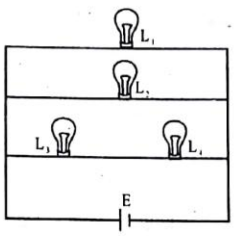
(c) 

(r) Bulbs will lit the brightest

(d) 

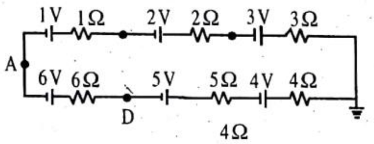
(s) Bulbs will lit with brightness lying between maximum and minimum value

2 In the shown circuit diagram, all the electric bulbs are identical. Then, match the entries of column I with the entries of column II.



Column I	Column II
(A) Current drawn by L_1 is,	(p) maximum
(B) Intensity of L_1 and L_2 is	(q) minimum
(C) Intensity of L_3 and L_4 is	(r) same
(D) Intensity of L_1 and L_4 is	(s) different

3 Six batteries of increasing e.m.f. and increasing internal resistance are connected in a circuit as shown in the given figure. Match the entries of column I with the entries of column II.



Column I	Column II
(A) Potential of point A	(p) Zero
(B) Potential of point B	(q) 2V
(C) Potential of point C	(r) 4V
(D) Potential of point D	(s) 6V
	(t) None

HOTS Subjective Questions :

DIRECTIONS : *Answer the following questions.*

1. How is a fuse put in an electric circuit ? State the purpose of using a fuse in a circuit.
2. A 60-W bulb is switched on in a room. A 240-W heater is also turned on in the same room. The voltage of the mains is 120V and the resistance of the connecting leads is 6Ω. What is the change in the voltage at the bulb when the heater is turned on.
3. Explain why an electric bulb becomes dim when an electric heater in parallel circuit is made on. Why dimness decrease after sometime ?
4. Why is tungsten metal selected for making filaments of incandescent lamp bulbs?
5. A heater joined in parallel with a 60 W bulb is replaced by a 100 W bulb, Will the rate of heat produced by the heater be more or less or remains the same ?
6. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through then. Why does the nichrome wire get heated first?
7. Two bulbs whose resistances are in the ratio 1 : 2, are connected in parallel to a source of constant voltage. What will be the ratio of power dissipation of these?
8. In a factory, an electric bulb of 500 W is used for 2 hours and electric bulb of 500 W is used for 2 hours and electric motor of 0.5 horse power is used for 5 hours everyday. Calculate the cost of using the bulb and motor for 30 days if cost of electrical energy is three rupees per unit.
9. An electric lamp is marked 100 W, 220 V. It is used for 5 hours daily. Calculate
   (i) its resistance while glowing
   (ii) energy consumed in kWh per day.
10. A torch bulb is rated 3V and 600 mA. Calculate its resistance if it is lighted for 4 hours.
11. A heater coil is rated 100 W, 200 V. It is cut into two identical parts. Both parts are connected together in parallel to the same source of 200V. Calculate the energy liberated per second in the new combination.
12. A 60 W electric lamp gives off energy in the form of light at a rate of 7.5 joule per second. What percentage of energy does the lamp transform into light energy?
13.

Refrigerator, electrical chip-pan, battery charger, loudspeaker, air-conditioner, electric drill, electroplating-vat

Choose only from the above electrical appliances those that make use of the
(a) chemical effect of an electric current.
(b) heating effect of an electric current.
(c) magnetic effect of an electric current.

14. This calculation is aimed at finding out how many joules there are in 1 kilowatt hour :
   1 watt second = 1 joule
   1 kilowatt second = ________ joules
   1 kilowatt minute = ________ × 60 joules
   1 kilowatt hour = ________ × 60 × 60 joules
   1 kilowatt hour = ________ joules
15. A man sits in a room for an hour watching T.V. There are four 100 W light bulbs switched on an the T.V. has a power rating of 150 W. The only electrical appliance in the room is an air conditioner which has a power rating of 450 W. Calculate the cost of electricity used in that room for the hour if 1 unit (kilowatt hour) costs 25c. It might help to divide the calculation as follows :
   Number of kilowatt hours for
   - light bulbs = ________
   - T.V. = ________
   - air conditioner = ________

   Total kilowatt hours = ________
   Total cost is ________
16. What does it mean to say that your car has a 12-volt battery?
17. A balloon may easily be charged to several thousand volts. Does that mean it has several thousand joules of energy? Explain.
18. Calculate the cost of electric bill of a house for the month of March. The following appliances were used in the house for the duration shown respectively. The cost of electrical energy is 50 paise per unit.
   6 – 100 W lamps 4h each
   5 – 60 W lamps 5h each
   1 – 750 W iron 2 h
   1 – 2 kW geyser 2h

SOLUTIONS

Brief Explanations of Selected Questions

Exercise 1

FILL IN THE BLANKS :

1. power, energy
2. ampere, hour
3. resistance, melting point
4. low, lead, tin, melts
5. series, live
6. separation
7. voltmeter
8. V × I × t
9. watt (W)
10. 1V
11. 3,600,000 J
12. Tungsten
13. voltage, current
14. electric power
15. electroplating
16. external resistance, internal resistance

TRUE / FALSE

1.	True	2.	True	3.	True	4.	True
5.	False	6.	True	7.	True	8.	False
9.	True	10.	False	11.	True	12.	False
13.	True	14.	True				

MATCH THE FOLLOWING :

1. (A) → q; (B) → r; (C) → p; (D) → s
2. (A) → r; (B) → s; (C) → p; (D) → q
3. (A) → q, (B) → p, (C) → r,s (D) → r, s

VERY SHORT ANSWER QUESTIONS :

1. Fuse is a thin wire which melts and breaks the electric circuit due to (i) overloading (ii) short circuit (iii) fluctuation in power supply.

2. (a) In series connection, total internal resistance (r) is equal to the sum of the internal resistances of the individual cells; $r = r_1 + r_2 + r_3$

   (b) In parallel connection, total internal resistance is equal to the sum of the reciprocals of individual internal resistances.

3. Gives the reading of energy consumed.

4. $J = \frac{W}{Q} = 4.18 \text{ J cal}^{-1}$

5. (i) The P.D. between two terminals of the cell, when current is drawn from it, i.e., the cell is in closed circuit, is called its terminal voltage (V).

   (ii) The electrolyte offers certain resistance to the flow of current. This is called the internal resistance of cell (r).

   (iii) The difference between EMF (E) of the cell and terminal voltage (V) of a cell is called lost voltage.

6. Watt-hour is a unit in which the amount of electric energy consumed by a device is measured.

7. The energy spent or work done an moving on electric charge through conductor is called electric energy or electric work.

8. The rate at which electric work is done is called electric power. In S.I., power = watt = 1 Js^{-1}.

9. The process of depositing a thin layer of desired metal over another metal by passing an electric current through some electrolyte is called electro plating.

10. Colliding electrons lose their K.E. as heat.

11. Given : $P = 100$ W, V = 120 V, Find R.

    From $P = \frac{V^2}{R}$, We have $R = \frac{V^2}{P} = \frac{(120V)^2}{100W} = 144\ \Omega$

12. Coils of electric toasters and electric irons are made of an alloy rather than a pure metal because
    (i) the resistivity of an alloy is much higher than that of pure metal, and (ii) an alloy does not undergo oxidation easily even at high temperature.

13. The cord of the electric heater made of copper does not glow because negligible heat is produced in it by passing current. It is due to its extremely low resistance.

14. The amount of current in a household circuit is more than the amount of current in a reading lamp as the current of the circuit is divided among all the appliances in a parallel household circuit.

15. There is AC flowing in the filament of the light bulb in our homes but DC flows in the bulbs of automobiles.

16. Resistance of the bulb

    $R = \frac{V}{I} = \frac{V^2}{IV} = \frac{V^2}{W}$ or $R = \frac{220 \times 220}{100} = 484$ ohm.

    Power consumed when connected to 110 volt source.

    $= \frac{V^2}{R} = \frac{110 \times 110}{484} = 25$ watt.

17. If n is the number of copper ions then $q = n \times 2e$

    $q = \text{It}$ or $n \times 2e = \text{It}$ $n = \frac{\text{It}}{2e} = \frac{0.5 \times 10}{2 \times 1.6 \times 10^{-19}}$

    $= 1.5625 \times 10^{19}$.

18. $P = \text{VI} = 220\text{V} \times 0.50\text{ A} = 110\text{ J/s} = 110\text{ W}$

19. 250W TV set in 1 hour.

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SHORT ANSWER QUESTIONS :

2. (i) Power, $P = V \times I$

$60 = V \times I$

$$V = \frac{60}{5} = 12 \text{ volts}$$

(ii) Resistance $= R = \frac{V}{I} = \frac{12}{5} = 2.4\ \Omega$

(iii) Energy consumed in 2 hours

$$= \frac{\text{watts}}{1000} \times \text{hr} = \frac{60}{1000} \times 2 = 0.12 \text{ kWh}$$

4. We know that the power input is, $P = VI$

Thus the current $I = P/V$

(a) When heating is at the maximum rate,
$I = 840\text{ W}/220\text{V} = 3.82\,A$
and the resistance of the electric iron is
$R = V/I = 220\text{V}/3.82\,A = 57.60\,\Omega$.

(b) When heating is at the minimum rate,
$I = 360\text{ W}/220\text{V} = 1.64\text{ A}$
and the resistance of the electric iron is
$R = V/I = 220\text{V}/1.64\text{ A} = 134.15\,\Omega$.

5. (i) 6A (ii) 75 kWh (iii) ' 165

6. Here, $R = 20\Omega,\ I = 5A,\ t = 30\text{s}$

Heat developed $= I^2Rt = 5 \times 5 \times 20 \times 30 = 15{,}000\text{ J} = 15\text{ kJ}$

7. (i) Equivalent resistance of 1Ω and 2Ω in series,
$R = 1\Omega + 1\Omega = 3\Omega$

Potential difference, $V = 6V$, Current, $I = \frac{V}{R} = \frac{6}{3} = 2A$

Current in series circuit is same.

$\therefore$ Current in 2Ω resistor $= 2A$

Power in 2Ω resistor, $P = I^2R = 2^2 \times 2 = 8\text{W}$

(ii) Potential difference across 2Ω resistor $= 4\text{V}$

$$\text{Power, } P' = \frac{V^2}{R} = \frac{4^2}{2} = 8\text{W}$$

$P : P' = 8\text{W} : 8\text{W} = 1 : 1$

8. Here, $R = 8\Omega$, $I = 15A$, $t = 2h = 2 \times 60 \times 60\text{s}$

Heat developed, $H = I^2Rt = (15)^2 \times 8 \times 2 \times 60 \times 60\text{ J}$

The rate at which heat is developed is power.

$$\text{Power} = \frac{\text{Heat developed } (I^2Rt)}{\text{Time taken (t)}}$$

$$= \frac{15 \times 15 \times 8 \times 2 \times 60 \times 60}{2 \times 60 \times 60} = 1800\text{ J/s}$$

9. $H = 100\text{ J}, R = 4, t = 1\text{s}, V = ?$

We have the current through the resistor as

$$I = \sqrt{H/Rt} = \sqrt{[100\text{J}/(4\Omega \times 1\text{s})]} = 5\text{A}$$

Thus the potential difference across the resistor V is given by $V = IR = 5A \times 4\Omega = 20\text{V}$

10. (a) electrical $\rightarrow$ sound (b) electrical sound
(c) electrical $\rightarrow$ light (d) electrical $\rightarrow$ mechanical energy

11. Current passing through the heater

$$I = \frac{V}{R} = \frac{250}{50} = 5A$$

Heat produced $= I^2Rt$ and Heat required $= mC\,\theta$.

Heat produced $= 5^2 \times 50 \times t$

$mC\,\theta = 2 \times 4 \times 10^3 \times (100 - 35) = 8 \times 10^3 \times 65$

Since, $5^2 \times 50 \times t = 8 \times 10^3 \times 65$

$$\therefore\ t = \frac{520 \times 1000}{1250} = 416\text{ s} = 6\text{ min } 56\text{ s}$$

12. 100 W bulb as $P \propto \frac{1}{R}$, $i \propto R$ (V is constant)

13. Since, $R \propto \frac{I}{P}\left(= \frac{V^2}{P}\right)$ toaster will have low resistance and bulb will have high resistance

14. Energy consumed in 30 days = 60 units

(i.e), $\frac{\text{days} \times \text{watt} \times \text{hours}}{1000} = 60$

$$\Rightarrow \frac{30 \times P \times 2}{1000} = 60\ ;\ P = 1000 \text{ watt.}$$

15. Energy consumed by five tubelights of 40 W for 5 hours in 1 day $= \frac{40}{1000} \times 5 = 1\text{ kWh}$

Energy consumed by an electric press of 500W for 4 hours in 1 day $= \frac{500 \times 4}{1000} = 2\text{ kWh}$

Energy consumed in 1 day $= 1 + 2 = 3$ kwh

$\therefore$ Total electrical energy consumed in 30 days
$= 3 \times 30 = 90\text{ kWh} = 90$ units

16. (i) Energy consumed in days
$= 100 \times 2 \times 60 + 5 \times 40 \times 4 \times 60$
$= 12000 + 48000 = 60000\text{ wh} = 60\text{ kWh}$

(ii) Cost of electricity $=$ ₹ $1.50 \times 60 =$ ₹ 90

17. It is the product of the voltage and the current which can flow through the device.

18. Heat dissipated depends upon (*i*) the square of current through the conductor (*ii*) the resistance of the conductor and (*iii*) the time for which current is passed.

19. During their motion the electrons collide with one another and hence lose some kinetic energy. This loss in kinetic energy is dissipated as heat across the conductor.

20. The power expended by a source is said to be 1 watt if one ampere of current flows through it under a potential difference of 1 volt.

21. So that it melts and breaks the circuit as soon as the safe limit of current is exceeded.

22. Because it has a high melting point and a high resistivity and does not easily react with air.

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LONG ANSWER QUESTIONS :

1. It goes beyond doubt that electricity plays a very important role in our lives. It is one of the most important and convenient sources of energy at homes and industries. However, we daily come across reports regarding hazards of electricity. Use of electricity can prove to be very dangerous if certain precautions and safety measures are not observed in the design of electrical devices and in handling them. The various safety measures to be taken are:
   (i) Use wires of high quality, proper amperage and good insulating material.
   (ii) Cover all naked wires and joints with insulating tape.
   (iii) All connections at plugs, switches, sockets must be tight.
   (iv) Replace any defective plugs, switches and sockets.
   (v) Never touch any part of the circuit without putting on rubber shoes or rubber gloves.
   (vi) Use fuse (now a days MCB) of proper rating and material.
   (vii) All electrical appliances must be properly earthed.
   (viii) Connect switches and fuse to live wires.
   (ix) Put out the main switch in case of short circuiting and fire.
   (x) Do not use water as fire extinguishers in case of fire due to electricity.

2. (i) By earthing we mean that the metallic body of an electric appliance is connected to thick, copper wire, which is buried deep in the earth and at its end is a copper plate surrounded by a mixture of charcoal and common salt.
   (ii) It is a kind of safety device which saves us from an electric shock, in case when the metal casing of the appliance happens to touch the live wire or due to short circuiting or leakage of electric current.
   Whenever an appliance which is earthed, gets short circuited, the current from the metal casing of the appliance flows into the earth which acts as an electric sink, i.e., its potential always remains zero. Due to the flow of heavy current the fuse in that circuit melts and disconnects the appliance from the circuit. So the user who happens to touch the appliance is protected from receiving any electric shock. Another advantage is that due to overheating the house wiring system is saved from being damaged and same time from being burnt out.
   (iii) A three core, cord having three wires coated with insulation of red, brown and green colour, in used for connecting the appliance to the mains for drawing current from the mains. At one end of the cord, red is connected to the pin marked L (live), the brown to the pin marked N (neutral) and green to thick pin of the plug. The three wires at the other end of the cord are connected to the appliance such that live and neutral wires are connected to the element and the earth wire is connected to the metal body of the appliance so as to earth it. Once the plug is put in the socket, the current through the appliance passes as soon as the switch is pressed. The live wire gets connected to the live wire of the mains. Neutral wire is connected to the neutral of the mains and the earth wire gets connected to the earth in the mains.

3. Given, power of one heater (P) = 250 watt, potential (V) = 100 volt, time (t) = 5 hours.
   (i) $P=\frac{V^2}{R}$; $R=\frac{V^2}{P}=\frac{100\times100}{250}=40\ \Omega$
   The three 250 watt heaters are connected in parallel then total current, $I=I_1+I_2+I_3$
   $=\frac{V}{R_1}+\frac{V}{R_2}+\frac{V}{R_3}=\frac{100}{40}+\frac{100}{40}+\frac{100}{40}$
   $=2.5+2.5+2.5=7.5\,A$
   (ii) The resistance of each heater is 40 Ω
   (iii) The energy supplied to the first heater is
   $H=I^2Rt=(2.5)^2\times40\times5$ Wh, As current flowing each heater is 2.5 A
   $\therefore H=6.25\times200\,\text{Wh}=1250\,\text{Wh}=\frac{1250}{1000}\,\text{kWh}=1.25\,\text{kWh}$
   Then three heaters in connection = 3 × 1.25 kWh
   = 3.75 kWh energy is used in the circuit.

4. (i) 2.08 Ω (ii) 4.16 V

5. The same work done in different forms produces the same quantity of heat in all cases.
   $W=JQ$
   $J=\frac{W}{Q}=4.18\ \text{J cal}^{-1}$

6. **1st Law** The mass of the substance deposited at the cathode is directly proportional to the quantity of electricity.
   $m\propto I$
   $m\propto It$
   $m\propto st$
   $m=Zit=ZQ$
   $m_1:m_2:m_3=z_1:z_2:z_3$
   2nd Law
   The same quantity of electricity passes through different electrolytes, the masses of ions liberated at the respective electrodes are proportional to the chemical equivalents.
   $m_1:m_2:m_3=E_1:E_2:E_3$
   $E_1:E_2:E_3=z_1:z_2:z_3$

7. (i) Filament offers high resistance to electric current. Electric energy is converted into light and heat energy.
   (ii) Discharge lamp is coated with fluorescent material from inside.
   High voltages are applied to coils, heat them which results in emission of electrons. Collision of electrons with mercury vapours produces lights.
   (iii) Glass tube having two electrodes fused to its. When high voltage is applied, gases inside the tube gets ionized.
   Accelerated ions collide with neutral gas atoms that produce glow.
   (iv) Produces high intensity light.
   Carbon rods having pointed tips at one end and separated by small gap.
   When 40 V to 60 V is applied across the carbon rods, glow is produced.

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(v) Form of a primary cell.
Consists of zinc container (cathode) at the centre of which a carbon rod (anode) is fixed. Dry paste of $NH_4Cl + ZnCl_2$ serves as an electrolyte.
Electrolyte is mixed with powdered coke.
$NH_4Cl \rightarrow NH_4^+ + Cl^-$
$2NH_4^+ + 2C^- \rightarrow 2NH_3 + H_2$
$H_2 + 2MnO_4 \rightarrow H_2O + MNO_3$
$Zn^{2+} + 2Cl^- \rightarrow ZnCl_2$
Here, chemical energy is converted in electrical energy.

Exercise 2

MULTIPLE CHOICE QUESTIONS :

1.	(d)	6.	(c)	11.	(d)	16.	(d)	21.	(a)
2.	(d)	7.	(b)	12.	(d)	17.	(b)	22.	(b)
3.	(d)	8.	(a)	13.	(b)	18.	(c)		
4.	(c)	9.	(c)	14.	(c)	19.	(d)		
5.	(d)	10.	(b)	15.	(d)	20.	(a)		

23. (d) Fuse wire should be such that it melts immediatley when strong current flows through the circuit. The same is possible if its melting point is low and resistivity is high.

24. (a) A heating wire should be such that it produces more heat when current is passed through it and also does not melt. It will be so if it has high specific resistance and high melting point.

25. (b) The rate of generation of heat, for a given potential difference is, $P = V^2/R$

26. (b) The rate of heat generation
$= I^2 R = I^2 (\rho\ell/\pi r^2)$.

27. (a) Heat produced, $H = V^2 t/R$ i.e. $H \propto 1/R$
so $H_1/H_2 = R_2/R_1$.

28. (a) In parallel combination, total power $P = P_1 + P_2$.

29. (d) First electro-chemical cell was designed by Allexandro de-Volta.

30. (d) **31.** (a) **32.** (b) **33.** (c)

34. (d) Dry cell being primary cell, cannot be recharged.

35. (c) Chemical effect of current is used in charging a car battery.

36. (d) The masses of the copper and silver deposited on cathodes of copper voltameter and silver voltameter are in the ratio of their chemical equivalent of copper and silver respectively.

37. (d)

38. (c) $m_{Ag}/m_{Zn} = E_{Ag}/E_{Zn} = 108/31$

or $m_{Ag} = m_{Zn} \times 108/31 = W \times 108/31$

39. (d)

40. (b) In electroplating, the metallic ions are positive, which are deposited on cathode.

41. (c) Electroplating does not help in making the metals become hard.

42. (a) Faraday's laws are based on the conversion of electrical energy into mechanical energy; which is in accordance with the law of conservation of energy.

43. (b) The amount of decomposition (i.e., mass of the substance liberated during electrolysis) is proportional to electro chemical equivalent of the substance.

44. (b) Current inside a copper voltameter is same as that of outside.

45. (a) $m = ZIt = Zq$ where I is the current and q is the amount of charge.

46. (c)

MORE THAN ONE CORRECT :

1. (a, d) **2.** (b, d) **3.** (b, c)

4. (a, c, d)
Potential difference across the accumulator $= 0.3 \times 4 = 1.2$ V < 1.5 V; hence cell is non-ideal. Internal resistance of the cell

$$= \frac{1.5 - 1.2}{0.3} = 1.0\Omega.$$

5. (a, b, c, d)
In case of non-ideal battery, an amount of energy is dissipated in the form of heat due to its internal resistance. If the battery is ideal then there is no internal drop hence reading of potentiometer and voltmeter will be equally correct.

6. (a, b, c)
Let $E_1 < E_2$.

$$\text{Current in the circuit} = I = \frac{E_1 - E_2}{r_1 + r_2}$$

$V_A - V_B = E_2 + Ir_2 = PD$ across each cell
Hence, $V_A - V_B > E_2$
Current flows in E_2 from the positive plate to the negative plate inside the cell and hence it absorbs energy.

7. (a, b, d)

In series, $I = \frac{nE}{nr} = \frac{E}{r}$ (i.e., I is independent of n)

In parallel, $I = \frac{E}{r/n} = \frac{nE}{r}$, i.e., $I \propto n$

After shorting by a wire having a constant resistance

$$I = E\left(R + \frac{r}{n}\right)$$

8. (a, d)
Equivalent e.m.f. of the battery is obtained by applying Kirchhoff's 2nd law to the two loops.

$$E_3 = \frac{E_1 R_2 + E_2 R_1}{R_1 + R_2}$$

9. (a, d)

10. (a, c)
Let $R_1 + R_2$ be the resistances of the two heaters and H be the heat produced.

$$\therefore \quad H = \frac{V^2}{R_1} t_1 = \frac{V^2}{R_2} t_2$$

When used in series, $H = \frac{V^2 t}{R_1 + R_2}$.

When used in parallel, $H = \left(\frac{V^2}{R_1} + \frac{V^2}{R_2}\right)t$

11. (a, c, d) **12.** (b, c, d) **13.** (a, c, d)

14. (a, c)

4Ω and 6Ω resistances are short circuited. Therefore, no current will flow through these two resistances. Current passing through the battery is $I = (20/2) = 10A$.
This is also the current passing in wire AB from B to A.
Power supplied by the battery.
$P = EI = (20)(10) = 200$ Watt
Potential difference across 4Ω resistance
= Potential difference across 6Ω resistance
$= 0$

FILL IN THE PASSAGE :

I 1. melt, 2. fuse, 3. live wire, 4. exceeds, 5. zero, 6. eliminated,

II 1. insulation, 2. touched, 3. body, 4. earth, 5. zero, 6. conducting, 7. earthing,

III 1. conductor, 2. free electrons, 3. lower potential, 4. higher potential, 5. colliding, 6. vibrate, 7. kinetic energy, 8. temperature,

PASSAGE BASED QUESTIONS :

Passage: I

1. (a) When the lamps are connected in parallel, then potential difference V across each lamp will be same and will be equal to potential necessary for full brightness of each bulb. Because illumination produced by a lamp is proportional to electric power consumed in it, and power consumed,

$$P_1 = \frac{V^2}{R_1} < \frac{V^2}{R_2} = P_2$$

Hence, illumination produced by 2nd bulb will be higher than produced by 1st bulb, i.e., bulb having lower resistance will shine more brightly.

2. (b) When R_1 burns out, then power is dissipated in R_2 only. Because internal resistance is quite low in lighting circuit, potential difference is still equal to V, hence, power dissipated in 2nd lamp, i.e..

$$\frac{V^2}{R_2} < \left(\frac{V^2}{R_1} + \frac{V^2}{R_2}\right).$$

i.e., net power consumed initially. In other words, net illumination will now decrease.

3. (b) When two lamps are connected in series, the potential difference across each lamp will be different but current I flowing through each lamp will be same.

Hence, $P_1 = I^2R_1 > I^2R_2 = P_2$

i.e., illumination produced by 1st lamp will be higher as compared to that produced by 2nd lamp, i.e., lamp having higher resistance will glow more brightly.

4. (b) When lamp of resistance R_2 burns out and only lamp of resistance R_1 is connected in the circuit then current flowing the circuit will change. Let new current be I'. Because potential difference still remains same (due to low internal resistance), hence

$$I'R_1 = I(R_1 + R_2)$$

$$\text{or } I' = \frac{I(R_1 + R_2)}{R_1}$$

If P' is the power consumed, then

$$P' = I'2R_1 = I^2 \frac{(R_1 + R_2)(R_1 + R_2)}{R_1}$$

When both the lamps were present then total power consumed was given by:

$P_S = P_1 + P_2 = I^2(R_1 + R_2)$. *i.e.*, $P' > P_S$

i.e., illumination gets increased when only one bulb is used.

5. (a) If a water pipe is given bend at some points, then it definitely reduces the flow of water in the pipe but this is not true in case of an electric current flowing in a conductor because electric current is established in a conductor due to drift motion of electrons in it along the line of the potential gradient. Hence, illumination is not affected due to bending along the length of supply wires.

Passage: II

1. (a) Potential gradient,

$$K = \frac{V_{AB}}{L} = \frac{I \times R}{L} = \frac{4 \text{ volt}}{(15+10) \text{ ohm}} \times \frac{10 \text{ ohm}}{50 \text{ cm}}$$

$$= \frac{40}{25 \times 50} \text{ Volt/cm}$$

$$\therefore E_2 = Kl = \frac{40}{25 \times 50} \times 31.25 = 1 \text{volt}$$

2. (d) When both the keys are closed: In the situation, R_1 is short circuited and terminal potential difference of E_2 is balanced by the potentiometer, i.e.,

$$\frac{E_2}{R_2 + r} \times R_2 = Kl = \frac{4 \times 10}{10 \times 50} \times 5$$

$$\frac{1 \times 5}{5 + r} = \frac{4}{50} \times 5 \text{ or } r = 7.5\Omega$$

3. (c) When key K_2 is open and K_1 is closed: In this case R_1 is short circuited and e.m.f. E_2 is balanced against potentiometer,

$$\text{i.e., } E_2 = \left[\frac{4}{10} \times \frac{10}{50}\right] \times l = \frac{1 \times 10 \times 50}{4 \times 10} = 12.5 \text{ cm}$$

4. (c) When key K_1 is open and K_2 is closed: In this case, R_1 is included in the potentiometer circuit and terminal potential difference of E_2 is balanced by the potentiometer.

$$i.e., \frac{E_2R_2}{R_2+r}=\left[\frac{4}{25}\times\frac{10}{50}\right]\times l$$

$$\text{or } \frac{1\times5}{5+7.5}=\frac{4}{1.25}\times l$$

or $l = 12.5$ cm

Passage: III

1. (d) Since, the power generated in the bulb equals the voltage across the bulb times the current through the bulb ($P = IV$), we need to know the current and voltage. Because the lower circuit loop contains only the battery and bulb 1, the bulb feels the battery's full voltage, 12 volts. So, by Ohm's law, a current,

$$I=\frac{V}{K}=\frac{12V}{3\Omega}=4\text{ amp}$$

flows through that bulb. Therefore, the bulb generates power,

$P = IV = (4\text{ A})(12\text{ V}) = 48\text{ W}$

2. (b) Most of the charges flowing around the circuit are valence electrons stripped off the metal atoms in the wire and light bulbs. A battery does not supply all of the charges. It merely pushes around charges already present in the circuit.

Statements (c) and (d) are both true. All charges flowing into the light bulb also flow back out; no curent gest used up. But inside the bulb, those charges lose energy. This lost electrical energy converts into light and heat. So, the current has lower potential after flowing through the bulb.

3. (c) If the battery has internal resistance, bulb 1 would dim. But here, screwing in bulb 2 does not prevent bulb 1 from feeling the full 12 volts produced by the battery. Both bulbs get a full does of that voltage. So, the bulb 2 turns on without lessening the brightness ofbulb 1. If you picked (b), you probably thought that the battery can supply only a certain amount of current.

According to this reasoning, bulb 2 draws current at the expense of bulb 1. But the battery does not supply all of the electrons flowing around the circuit. It merely pushes around electrons already present in the metal wires and bulb filaments, as mentioned in earlier question. Screwing in bulb 2 allows the valence electrons in that branch of the circuit to join the current.

4. (d) The total current through the battery is simply,

$$I=\frac{V}{R_{eq.}}$$

where, $R_{eq.}$ denotes the equivalent resistance of the whole circuit. These two light bulbs are wired in parallel; any given electron flowing around the circuit passes through one bulb or the other, but not both. So, we must use the inparallel formula,

$$\frac{1}{R_{eq.}}=\frac{1}{R_1}+\frac{1}{R_2}=\frac{1}{3}+\frac{1}{6}=\frac{1}{2\Omega}$$

and hence, $R_{eq.} = 2\Omega$

$$\text{So, } I=\frac{V}{R_{eq.}}=\frac{12V}{2\Omega}=6\text{ amp}$$

Intuitively, the equivalent resistance of two in-parallel resistors is less than either individual resistance because the current can split itself between two paths.

5. (c)

Assertion & Reason :

1. (b) Glow = Power $(P) = I^2R$

$$\therefore \frac{dP}{P}=2\left(\frac{dI}{I}\right)=2\times0.5=1\%$$

2. (b) Power loss $= i^2R=\left(\frac{P}{V}\right)^2 R$

[P = Transmitted power]

3. (b) $P=\frac{V^2}{R}$; $R\propto\frac{1}{P}$ (same rated voltage)

4. (d) In tube light majority portion of radiation comes under visible region while bulb radiation consists of visible, ultraviolet, infrared radiation giving less visible part.

5. (c) Here, $P=\frac{E^2}{R}$, so $P\propto R$ only when I is constant. Here I increases as R is decreased. Hence the reason is wrong.

6. (c) As $R = V/I$ and P = VI, by measuring V and I simultaneously in circuit we can measure both resistance and power, using the given relation.

7. (a)

Multiple Matching Questions :

1. (A) → q ; (b) → r; (C) → p,s (D) → s
2. (A) → p; (B) → p;r (C) → q,r; (D) → s
3. (A) → p; (B) → p; (C) → p; (D) → p

Hots Subjective Questions :

1. A fuse is safety device having a short length of a thin wire of tin-lead alloy, that melts and breaks the circuit if the current exceeds a safe value.
2. The resistance of bulb and heater we respectively 240Ω and 60 Ω , and these are connected in parallel. Their equivalent resistance is 48 Ω . When only bulb is switched on, current from the mains is

$\frac{120\text{V}}{(240+6)\,\Omega}=0.488\text{ A}$. When heater is also turned on, current becomes $\frac{120\text{V}}{(48+6)\,\Omega}=2.22\text{ A}$.

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3. The resistance of a heater coil is less than that of electric bulb filament. When heater is switched on in parallel, more current start flowing through the heater coil and current through the bulb filament decreases making it dim.
After sometime, when heater coil becomes hot its resistance increases. As a result current through the heater coil decreases and the current through the bulb filament increases and thus dimness of the bulb decreases.

4. Tungsten metal has high resistivity and high melting point.

5. Resistance of 60 W bulb is more than in 100 W bulb. So equivalent resistance of the network drops on placing 100 W bulb and so the power or heat $\left(\frac{V^2}{R}t\right)$ is more

6. Nichrome has greater resistivity.

7. Since, $P = \frac{V^2}{R}$, $P_1 : P_2 = R_2 : R_1 = 2 : 1$

8. Electrical energy consumed in 30 days
$= 500 \times 2 \times 30 + 0.5 \times 746 \times 5 \times 30$ (1 hp = 746 W)
$= 30000 + 55950 = 85950$ Wh $= 85.95$ kW h
Cost of energy $= 3 \times 85.95 =$ ₹ 258.

9. (i) $R = \frac{V^2}{P} = \frac{220^2}{100} = 484\Omega$
(ii) Energy consumed per day
$= P \times t = 100 \times 5 = 500$ Wh $= 0.5$ k Wh.

10. Given : V = 3 Volt,
$I = 600\text{ mA} = 600 \times 10^{-3}\text{ A} = 0.6\text{ A}$
From Ohm's law
$V = IR \Rightarrow R = \frac{V}{I} = \frac{3}{0.6} = \frac{30}{6} = 5\Omega$

11. Resistance of heater coil
$\frac{V^2}{P} = \frac{200^2}{100} = 400\Omega$
Resistance of each cut part = 200Ω
When connected in parallel, the net resistance will be 100Ω
Energy liberated per second
$= \frac{V^2}{R} = \frac{200^2}{100} = 400\,\Omega$ joule

12. Power of lamp = 60 W
Light liberated = 7.5 W
% of transfer $= \frac{7.5}{60} \times 100 = 12.5\%$

13. (a) Battery charger, electroplating-vat
(b) electric chip-pan
(c) refrigerator, air conditioner, electric drill, loudspeaker

14. (a) 1 kilowatt second = 1000 joules
1 kilowatt minute $= 1000 \times 60 \times 60$ joules
1 kilowatt hour $= 1000 \times 60 \times 60$ joules
$= 3600000$ joules

15.
Light bulbs	= 1000
T.V.	= 0.15 kWh
air conditioner	= 0.45 kWh
Total	= 1.0kWh = 25¢

16. It means that one of the battery terminals is 12V higher in potential than the other one. Soon we will see that it also means that, when a circuit is connected between these terminals, each coulomb of charge in the resulting current will be given 12 J of energy as it passes through the battery (and 12 J of energy "spent" in the circuit).

17. No, it doesn't mean that the balloon has several thousand joules of energy always. It can have several thousand joules of energy only if the balloon acquires high charge.

18. Energy consumed by different appliances is

100W lamps, $6 \times 100 \times 4$	= 2400 Wh
60 W lamps, $5 \times 60 \times 5$	= 1500 Wh
750W electric iron, 750×2	= 1500 Wh
2 kW geyser, 2000×2	= 4000 Wh
	9400 Wh

No. of units consumed per day $= \frac{9400}{1000}$ Wh $= 9.4$ kWh
Total consumption for 31 days $= 9.4 \times 31 = 291.4$ kWh
Total cost of the bill $= 291.4 \times \frac{1}{2} =$ ₹ 145.70

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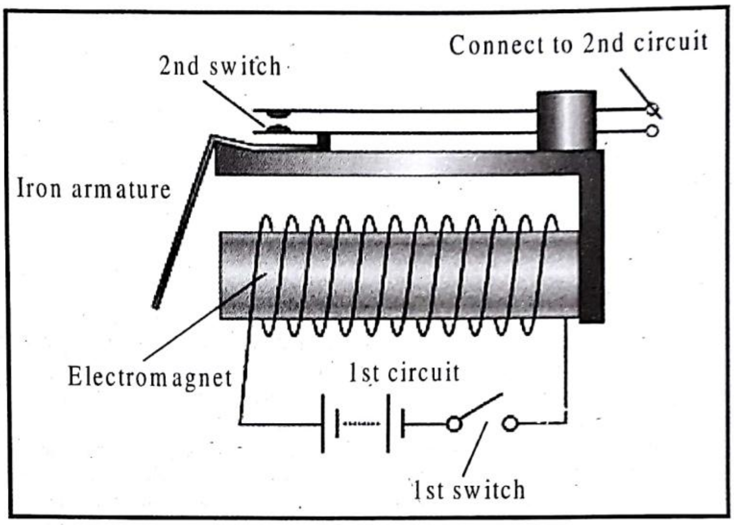
chapter 6



ELECTROMAGNETISM

Introduction

The term magnetism comes from Magnesia, the name of an ancient city in Asia Minor, where the Greeks found certain very unusual stones more than 2000 years ago. These stones, called lodestones, possess the unusual property of attracting pieces of iron. Such magnets were first fashioned into compasses and used navigation by the Chinese in the twelfth century A.D.

In the sixteenth century, William Gilbert, Queen Elizabeth's physician, made artificial magnets by rubbing pieces of iron against lodestones. He suggested that a compass always points north and south because the earth itself shows the magnetic properties. Later in 1750, John Michaell in England found that magnetic poles obey the inverse-square law, and his results were confirmed by Charles Coulomb. The subjects of magnetism and electricity developed almost independently until 1820, when a Danish physicist named Hans Christian Oersted discovered, in a classroom demonstration, that an electric current affects a magnetic compass. He saw that magnetism was related to electricity. Shortly thereafter, the French physicist Andre Marie Ampere proposed that electric currents are the source of all magnetic phenomena. This chapter is all about how electricity is connected with magnetism.

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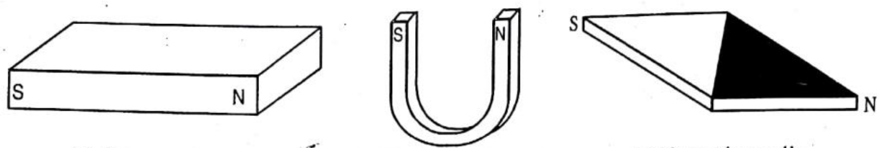
PERMANENT MAGNETS

Magnets produced from magnetic materials are called Artificial magnets. They can be made in a variety of shapes and sizes and are used extensively in electrical apparatus.



(a) Bar magnet (b) U-shape magnet (c) Magnetic-needle

Fig. 6.1

Artificial magnets are generally made from special iron or steel alloys which are usually magnetized electrically. The material to be magnetized is inserted into a coil of insulated wire and a heavy flow of electrons is passed through the wire. Magnets can also be produced by stroking a magnetic material with magnetite or with another artificial magnet. The forces causing magnetization are represented by magnetic lines of force.

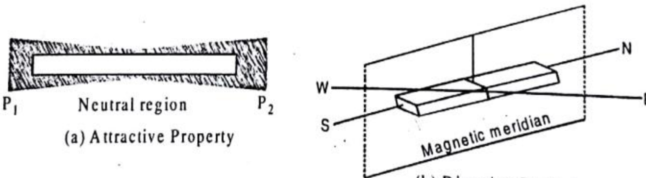
Artificial magnets are usually classified as permanent or temporary, depending on their ability to retain their magnetic properties after the magnetizing force has been removed. Magnets made from substances, such as hardened steel and certain alloys which retain a great deal of their magnetism, are called permanent magnets. These materials are relatively difficult to magnetize because of the opposition offered to the magnetic lines of force as the lines of force try to distribute themselves throughout the material. The opposition that a material offers to the magnetic lines of force is called **reluctance**. All permanent magnets are produced from materials having a high reluctance.

A material with a low reluctance, such as soft iron or annealed silicon steel, is relatively easy to magnetize but will retain only a small part of its magnetism once the magnetizing force is removed. Materials of this type that easily lose most of their magnetic strength are called temporary magnets. The amount of magnetism which remains in a temporary magnet is referred to as its residual magnetism. The ability of a material to retain an amount of residual magnetism is called the **retentivity** of the material.

Magnets are also described in terms of the **permeability** of their materials, or the ease with which magnetic lines of force distribute themselves throughout the material. A permanent magnet, which is produced from a material with a high reluctance, has a low permeability. A temporary magnet, produced from a material with a low reluctance, would have a high permeability.

PROPERTIES OF BAR MAGNETS

(1) Attractive Property and Poles : When a magnet is dipped into iron fillings it is found that the concentration of iron filings, i.e., attracting power of the magnet is maximum at two points near the ends and minimum at the centre. The places in a magnet where its attracting power is maximum are called poles while the place of minimum attracting power is called the neutral region.



(a) Attractive Property (b) Directive-Property

Fig. 6.2

(2) Directive Property and N-S Poles : When magnet is suspended its length becomes parallel to N-S direction. The pole pointing north is called the north pole while the other pointing south is called the south pole.

(3) Opposite poles (N and S) attract and like poles (N and N, or S and S) repel.

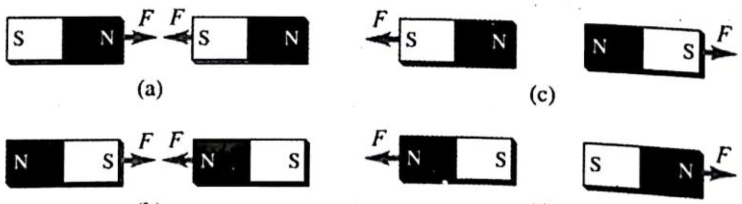


Fig. 6.3

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(4) Magnetic Axis and Magnetic Meridian : The line joining the two poles of a magnet is called magnetic axis and the vertical plane passing through the axis of a freely suspended or pivoted magnet is called magnetic meridian.

(5) Magnetic Length (2ℓ) : The distance between two poles along the axis of a magnet is called its effective or magnetic length. As poles are not exactly at the ends, the effective length is lesser than the actual length of the magnet.

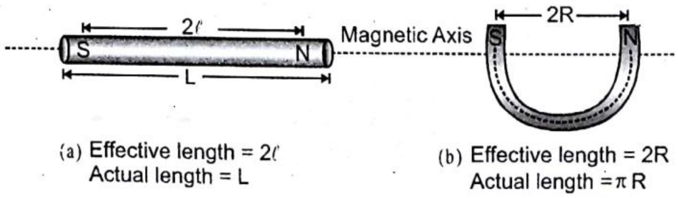


Fig. 6.4

(6) Poles Exist in Pairs : In a magnet the two poles are found to be equal in strength and opposite in nature. If a magnet is broken into number of pieces, each piece becomes a magnet with two equal and opposite poles. This shows that monopoles do not exist.

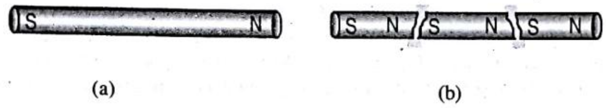


Fig. 6.5

(7) Repulsion is a Sure Test of Polarity : A pole of a magnet attracts the opposite pole while repels similar pole. A sure test of polarity is repulsion and not attraction, as attraction can take place between opposite poles or a pole and a piece of unmagnetised magnetic material due to 'induction effect'.

(8) Magnetic Induction : A magnet attracts certain other substances through the phenomenon of magnetic induction i.e., by inducing opposite pole in a magnetic material on the side facing it as shown in fig.

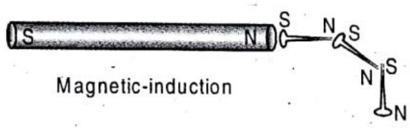
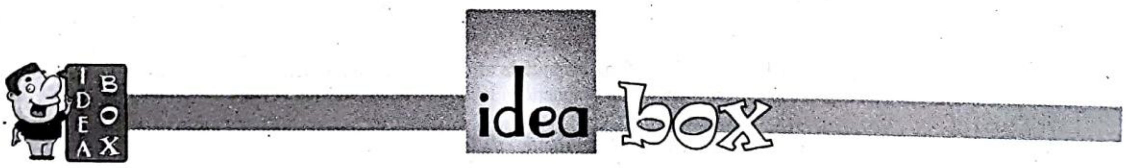


Fig. 6.6



- *Fix a sheet of white paper on a drawing board using some adhesive material. • Place a bar magnet in the centre of it.*
- *Sprinkle some iron filings uniformly around the bar magnet. A salt-sprinkler may be used for this purpose.*
- *Now tap the board gently. • Note the observation.*

Interesting Fact

Seeds of two tomatoes varieties Rocco and Monza were treated by passing them through an artificial magnetic field (MF) with a constant defined velocity before seeding. The seedlings obtained from MF treated and non MF-treated seeds were planted into the MF treated and non MF-treated plots. They were irrigated by MF-treated and non MF treated water.

Observations were made on early-yield, total-yield, beginning of blooming, and quality of fruit. While significant differences were not observed in Rocco, important MF effects were clearly seen on Monza. Yield increases on Monza in magnet treated plots were around 28–51 percent, especially in early yields, and Monza bloomed three-four days earlier.

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Pole strength and magnetic moment of a magnet

The strength of attracting a magnetic material by a magnetic pole is measured by pole strength, generally denoted by m. The north and south poles of a magnet are said to be associated with the pole strengths $+m$ and $-m$, respectively, each of which is a scalar, having the dimensional formula $[AL]$ and SI unit Am. Each pole strength is imagined to be distributed over the entire cross-section of the magnet. Therefore, if the magnet is cut along it's length into the two equal parts, each part will have it's poles of the strengths $+m/2$ and $-m/2$, respectively, and if the magnet is cut perpendicular to it's length into the two equal parts, each part will have it's poles of same initial strengths $+m$ and $-m$, respectively.

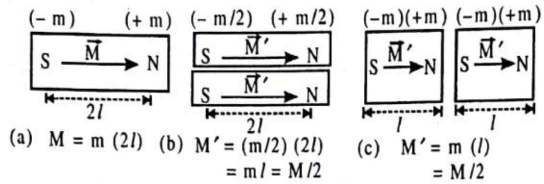

Fig. 6.7

The magnetic moment of a magnet is defined as a vector $\vec{M}$ whose magnitude is

$$M = n\,(2l)$$

where m is the pole strength of magnet and $2l$ is the effective length of magnet and whose direction is from the south pole to the north pole. It has the dimensional formula $[AL^2]$ and SI unit Am^2. If the magnet is cut along it's length, or perpendicular to its length, into the two equal parts, each part will have it's magnetic moment of magnitude one-half of that of the original magnetic moment, as shown above.

MAGNETIC FIELD

The space around a magnet (or a current carrying conductor) in which its magnetic effect can be experienced is called the magnetic field. It is a quantity that has both direction and magnitude. Pictorically it is represented by magnetic lines of forces. Tangent to magnetic lines of forces gives direction of magnetic field at that point. No two magnetic lines of force intersect each other.

The magnetic field in a region is said to be uniform if the magnitude of its strength and direction is same at all points in that region.

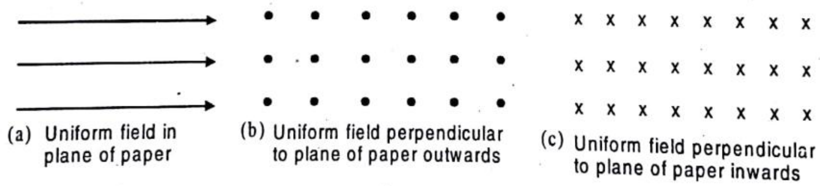

Fig. 6.8

A magnetic field in a region is said to be uniform if the magnitude of its strength and direction is same at all the points in that region. The strength of magnetic field is also known as magnetic induction or magnetic flux density.

The SI unit of strength of magnetic field is Tesla (T)

1 Tesla = 1 newton ampere^{-1} metre^{-1} ($NA^{-1}m^{-1}$) = 1 Weber metre^{-2} ($Wb\,m^{-2}$)

The cgs unit is gauss (G), 1 gauss (G) = 10^{-4} Tesla (T).

COULOMB'S LAW IN MAGNETISM

This law defines the force F between the two magnetic poles of the strengths m_1, m_2 at a distance r apart in a medium as

$$F = \left(\frac{\mu}{4\pi}\right)\left(\frac{m_1 m_2}{r^2}\right) \quad \text{(SI)} \qquad F = \left(\frac{1}{\mu}\right)\left(\frac{m_1 m_2}{r^2}\right) \quad \text{(CGS)}$$

where μ is the permeability of medium and $\mu = \mu_0 = 4\pi \times 10^{-7}\ N/A^2$ in SI and $\mu = \mu_0 = 1$ (unitless) in CGS. Evidently, the force F is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance r. It acts along the line joining the two magnetic poles. It is attractive for the unlike magnetic poles and repulsive for the like magnetic poles. It depends on the medium in which the magnetic poles are situated.

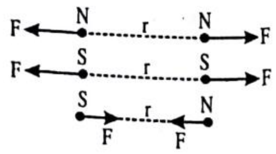

Fig. 6.9

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CHECK Point

A friend tells you that a refrigerator door, beneath its layer of white-painted plastic, is made of aluminum. How could you check to see if this is true (without any scraping) ?

SOLUTION

I will bring a magnet and make it touch with the refrigerator door. If the magnet shows a feeble attraction with it then I can say that it is aluminum.

ILLUSTRATION 6.1

Four identical bar magnets, each of magnetic moment M, are arranged to form a square, as shown. Calculate the resultant magnetic moment of the system.

SOLUTION:

The magnetic moments of the given four identical bar magnets are acting along the sides of a square, as shown. The resultant of each of the two pairs of magnetic moments, *i.e.*, (1, 4) and (2, 3), is $M\sqrt{2}$ and it is represented by the same diagonal of the square. Therefore, the resultant of all the four magnetic moments, taken together, is $2\sqrt{2}M$, which is acting along the diagonal.

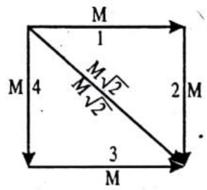

Fig. 6.10

MAGNETIC FIELD DUE TO MAGNETIC POLE

In SI, the magnetic induction $\vec{B}$ due to a magnetic pole is defined at a point at a distance r as the force per unit north pole placed there, having the magnitude

$$B = \left(\frac{\mu}{4\pi}\right)\left(\frac{m}{r^2}\right) \quad \text{tesla}$$

$$\Rightarrow \quad H = \frac{B}{\mu} = \left(\frac{1}{4\pi}\right)\left(\frac{m}{r^2}\right) \quad \text{A/m}$$

and direction away for north pole and towards for the south pole. In CGS, the magnetic field intensity $\vec{H}$ due to a magnetic pole is defined at a point at a distance r as the force per unit north pole placed there, having the magnitude

$$H = \left(\frac{1}{\mu}\right)\left(\frac{m}{r^2}\right) \text{oersted} \Rightarrow B = \mu H = \left(\frac{m}{r^2}\right) \text{gauss}$$

and direction away for the north pole and towards for the south pole.

FORCE ON MAGNETIC POLE PLACED IN MAGNETIC FIELD

In SI, the force a magnetic pole of strength m placed in a magnetic field $\vec{B}$ is

$$\vec{F} = \pm m\vec{B}$$

where + sign is for the north pole and – sign is for the south pole. Thus, the force is in the direction of $\vec{B}$ for the north pole and in the opposite direction for the south pole **(Fig. 6.11)**.

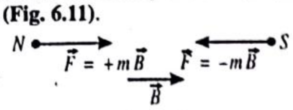

Fig. 6.11

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In CGS, the force on a magnetic pole of strength m placed in a magnetic field $\vec{H}$ is

$$\vec{F} = \pm m\vec{H}$$

where + sign is for the north pole and – sign is for the south pole. Thus, the force is in the direction of $\vec{H}$ for the north pole and in the opposite direction for the south pole. **(Fig. 6.11)**

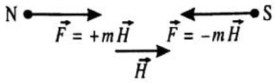

Fig. 6.12

MAGNETIC FIELD DUE TO A BAR MAGNET

End-on Position

The magnetic field $\vec{B}$ at a point P on the axis of a bar magnet at distance r form it's mid point O is given by

$$\vec{B} = \vec{B}_N + \vec{B}_s$$

$$\Rightarrow \quad B = B_N - B_S$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{m}{(r-l)^2} - \frac{\mu}{4\pi}\frac{m}{(r+l)^2} = \left(\frac{\mu}{4\pi}\right)\frac{2Mr}{(r^2-l^2)^2} \approx \left(\frac{\mu}{4\pi}\right)\left(\frac{2M}{r^3}\right) \text{for } l << r$$

which is having the direction parallel to the magnetic moment $\vec{M}$ of the bar magnet.

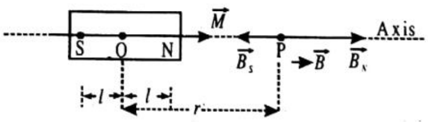

Fig. 6.13

Broadside-on Position

The magnetic field $\vec{B}$ at a point P on the equator of the bar magnet at a distance r from it's mid point O is given by

$$\vec{B} = \vec{B}_N + \vec{B}_s$$

$$\Rightarrow \quad B = 2B_N \cos\theta$$

$$= 2B_s \cos\theta$$

$$= 2\left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2+l^2)} \cdot \frac{l}{\sqrt{(r^2+l^2)}} = \left(\frac{\mu}{4\pi}\right)\frac{M}{(r^2+l^2)^{3/2}} \approx \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right) \text{ for } l << r$$

which is having the direction antiparallel to the magnetic moment $\vec{M}$ of the bar magnet. Evidently, the magnetic field at the broadside-on position is one-half of that at the end-on position for the same distance r from the mid point O of the bar magnet.

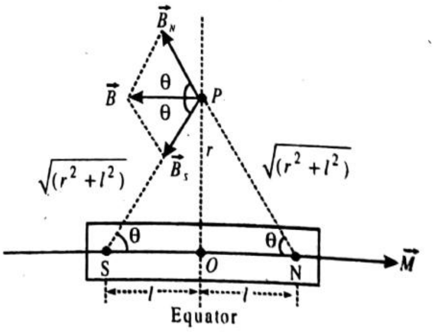

Fig. 6.14

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Any Other Position

The magnetic moment $\vec{M}$ of bar magnet has the two components, namely, $M\cos\theta$ and $M\sin\theta$, as shown. The point P is neither on the axis nor on the equator of bar magnet but having any other position at a distance r from the mid point O. It's position is end-on for the component $M\cos\theta$ and broadside-on position for the component $M\sin\theta$. Therefore, the magnetic field $\vec{B}$ at the point P is given by

$$\vec{B} = \vec{B}_r + \vec{B}_\theta$$

$$\Rightarrow \quad B = \sqrt{(B_r^2 + B_\theta^2)}$$

$$= \sqrt{\left[\left(\frac{\mu}{4\pi}\right)^2\left(\frac{2M\cos\theta}{r^3}\right)^2 + \left(\frac{\mu}{4\pi}\right)^2\left(\frac{M\sin\theta}{r^3}\right)^2\right]}$$

$$= \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right)\sqrt{(4\cos^2\theta + \sin^2\theta)}$$

$$= \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right)\sqrt{(1+3\cos^2\theta)}$$

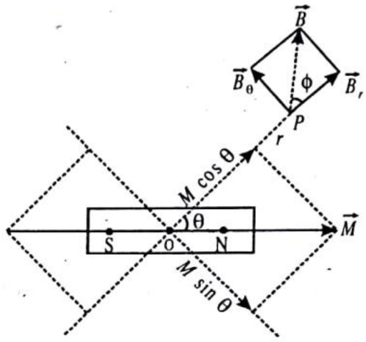

Fig. 6.15

whose direction is inclined at an angle $(\phi + \theta)$ with the magnetic moment $\vec{M}$, where

$$\tan\phi = \frac{B_\theta}{B_r} = \left(\frac{1}{2}\right)\tan\theta$$

FORCE AND TORQUE ON BAR MAGNET PLACED IN MAGNETIC FIELD

Uniform Magnetic Field

When a bar magnet is placed in a uniform magnetic field $\vec{B}$ at an angle θ, the total force one it becomes

$$\vec{F} = \vec{F}_N + \vec{F}_S = (+m)\ (+m)\vec{B} + (-m)\vec{B} = 0$$

and hence, it does not undergo any translatory motion.

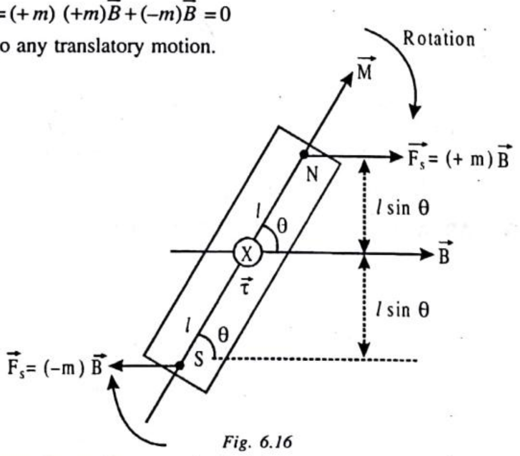

Fig. 6.16

The total torque on the bar magnet due to the magnetic field is

$$\vec{\tau} = \vec{M} \times \vec{B}$$

whose magnitude is

$$\tau = (mB)\,l\sin\theta + (mB)\,l\sin\theta$$
$$= (2ml)\,B\sin\theta$$
$$= MB\sin\theta$$

and whose direction is perpendicular to the plane of figure and inwards, as shown. This torque produces the rotatory motion of the bar magnet in the clockwise direction.

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Non-uniform Magnetic Field

When the bar magnet is placed in a non-uniform magnetic field $\vec{B}$ at an angle θ, the total force on it becomes

$$\vec{F} = \vec{F}_N + \vec{F}_S$$

$$= (+m)\,\vec{B} + (-m)\vec{B'} = m(\vec{B} - \vec{B'}) \neq 0$$

which produces the translatory motion of the bar magnet in its' direction. The total torque on the bar magnet due to the magnetic field is

$$\vec{\tau} = \vec{M} \times \vec{B}_{av}$$

whose magnitude is

$$\tau = (mB)\,l \sin\theta + (mB')\,l \sin\theta$$

$$= (2ml)\left(\frac{B+B'}{2}\right)\sin\theta = MB_{av}\sin\theta$$

where B_{av} is the average magnetic field, and whose direction is perpendicular to the plane of figure and inwards, as shown. This torque produces the rotatory motion of the bar magnet in the clockwise direction.

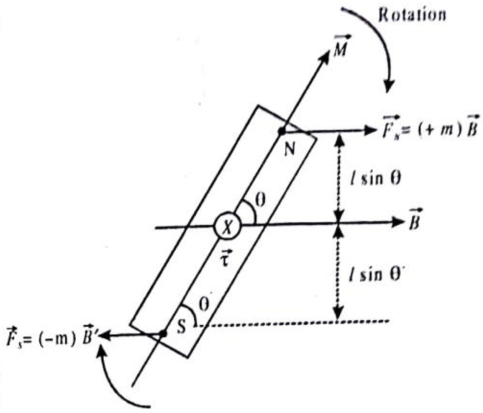

Fig. 6.17

POTENTIAL ENERGY OF BAR MAGNET PLACED IN MAGNETIC FIELD

The potential energy of a bar magnet of the magnetic moment $\vec{M}$ placed in a magnetic field $\vec{B}$ is

$$U = U_N + U_S$$
$$= (+m)\,V_N + (-m)\,V_S$$
$$= (-m)\,(V_S - V_N)$$
$$= (-m)\,(B\cos\theta)\,2l$$
$$= -MB\cos\theta$$
$$= -\vec{M}.\vec{B}$$

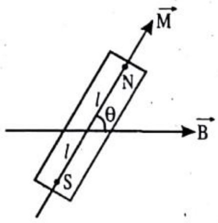

Fig. 6.18

where U_N, U_S are the potential energies of the north pole and south pole of the bar magnet, respectively, and V_N, V_S are the magnetic potentials at the positions of the two poles, respectively. Evidently, U may be positive, or zero, or nagative, depending on the angle θ. U is maximum and equal to $+MB$ for $\theta = 180°$ and minimum and equal to $-MB$ for $\theta = 0°$. Therefore, the position $\theta = 0$ of the bar magnet is that of the stable equilibrium.

WORK DONE IN ROTATING BAR MAGNET IN MAGNETIC FIELD

The work done in rotating a bar magnet of the magnetic moment $\vec{M}$ from it's initial position θ_I to a final position θ_F in a magnetic field $\vec{B}$ is

$$W = U_F - U_I = (-MB\cos\theta_F) - (-MB\cos\theta_I) = MB\,(\cos\theta_I - \cos\theta_F)$$

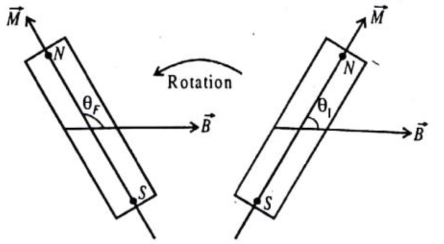

Fig. 6.19

For example, when the bar magnet is rotated through 180° from the position of stable equilibrium (θ = 0°), then the work done is

$$W = MB\,(\cos 0° - \cos 180°) = 2MB$$

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CHECK Point

- **One way to make a compass is to stick a magnetized needle into a piece of cork and to float it in a glass bowl full of water. The needle will align itself with the horizontal component of the earth's magnetic field. Since the north pole of this compass is attracted northward, will the needle float toward the north side of the bowl ? Defend your answer.**

SOLUTION

Yes, the north pole of the needle will float toward the north side of the bowl. The earth is a huge magnet whose north pole is towards the geographic south and the south pole is towards the geographic north. So, the north pole of the needle will align towards the south pole of the earth's magnet which is northward. Therefore, the north pole of the needle will tend to float toward the north side of the bowl.

ILLUSTRATION 6.2

The magnetic field due to a small bar magnet at a distance of 24 cm on its equator is B and the magnetic field at a distance d on it's axis is 16 B. Then, what is the distance d ?

SOLUTION:

The magnetic field due to the small bar magnet of the magnetic moment M at a distance of 0.24 m on its equator is

$$B=\left(\frac{\mu_0}{4\pi}\right)\frac{M}{(0.24)^3}$$

The magnetic field at a distance d on the axis of magnet is $16B=\left(\frac{\mu_0}{4\pi}\right)\frac{2M}{(d)^3}$

Dividing the two equations, we have

$$16=2\left(\frac{0.24}{d}\right)^3$$

$$\Rightarrow \quad d=0.12\,\text{m}=12\,\text{cm}.$$

Terresterial Magnetism

William Gilbert suggested that earth itself behaves like a huge magnet. This magnet is so oriented that its S pole is towards geographic north and N pole is towards the geographic south.

The earth behaves as a magnetic dipole inclined at small angle 11.5° to the earth's axis of rotation with its south pole pointing geographic north. The idea of earth having magnetism is supported by following facts.

(a) A freely suspended magnet always comes to rest in N-S direction. (b) A piece of soft iron buried in N-S direction inside the earth acquires magnetism. (c) Existence of neutral points. When we draw field lines of bar magnet we get neutral points where magnetic field due to magnet is neutralized by earth's magnetic field.

The magnetic field at the surface of earth ranges from nearly 30 μT near equator to about 60 μT near the poles. The magnetic field on the axis is nearly twice the magnetic field on the equatorial line.

Cause of earth's magnetism

Sir William Gilbert first suggested the existence of a powerful magnet inside the earth. This is not possible because.

(a) Temperature inside earth is so high that it will not be possible for magnet to retain magnetism.

(b) If there was a magnet inside the earth then position of earth's magnetic poles would have not changed.

(c) The process of magnetisation of this magnet is not understood.

Grover suggested that earth's magnetism is due to flow of current near outer surface of earth. These currents are produced due to sun. The hot air rising from regions near equator while going towards north and south hemispheres gets electrifield. These then magnetise ferromagnetic materials near the surface of earth.

According to another view earth's core has many conducting materials like iron and nickel in molten state. Conventional currents are produced in this semi fluid core due to rotation of earth about its axis which generates magnetism.

Another view says magnetism is due to presence of ionised gases in atmosphere. The high energy sun rays ionize gas atoms in upper layer of atmosphere. The radioactivity of atmosphere and cosmic rays also ionize the gases. Strong electric currents flow due to rotation of earth producing magnetism.

Thus most likely cause of earth's magnetism is the motion and distribution of charged materials in and outside the earth.

Some definitions

Geographic Axis : It is straight line passing through the geographic poles of the earth. It is the axis of rotation of the earth. It is known as polar axis.

Geographic Meridian : It is a vertical plane passing through geographic north and south poles of the earth.

Geographic Equator : A great circle on the surface of the earth in a plane perpendicular to geographical axis is called geographic equator. All places on geographic equator are at equal distances from geographical poles.

Magnetic Axis : It is a straight line passing through the magnetic poles of the earth. It is inclined to geographic axis at nearly 11.5°.

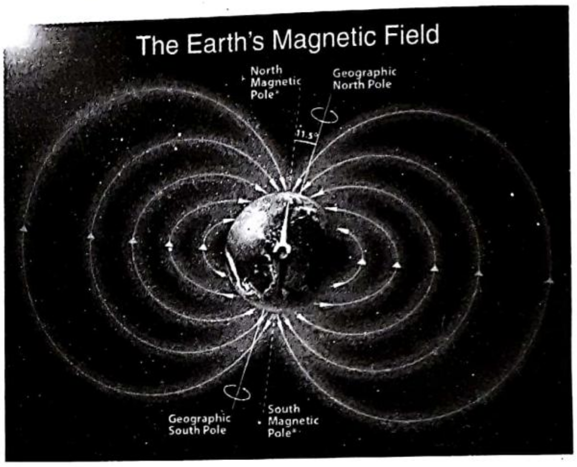

Fig. 6.20

Magnetic Meridian : It is a vertical plane passing through the magnetic north and south poles of the earth.

Magnetic Equator : A great circle on the surface of the earth in a plane perpendicular to magnetic axis is called magnetic equator. All places on magnetic equator are at equal distance from magnetic poles.

COMPONENTS OF EARTH'S MAGNETIC FIELD

The resultant magnetic field $\vec{B}$ of earth at a place has the two components, namely, the vertical component B_V and horizontal component B_H. The component B_V has the vertical direction which is downwards in the northern hemisphere and upwards in the southern hemisphere. The component B_H has the horizontal direction which is from the south to the north everywhere.

$$B_V = B\sin\theta$$

$$B_H = B\cos\theta$$

$$B = \sqrt{\left(B_V^2 + B_H^2\right)}$$

$$\tan\theta = \frac{B_V}{B_H}$$

The vertical component $B_V = 0$ at the magnetic equator and the horizontal component $B_H = 0$ at the magnetic north and south poles of earth. At Delhi, $B_H = 35\ \mu T = 0.35 G$.

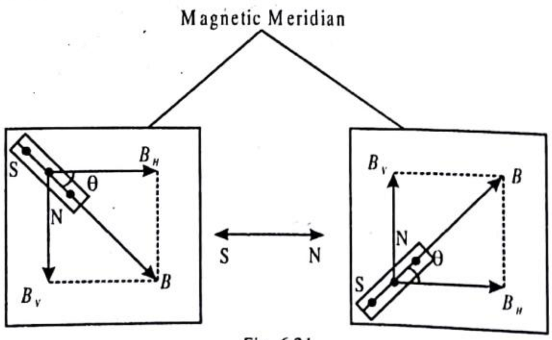

Fig. 6.21

Angle of Dip, or Inclination, θ

At a place, the angle θ which the resultant magnetic field $\vec{B}$ of earth makes with the horizontal is called the angle of dip, or inclination. A freely-suspended magnet will keep it's axis at this angle θ with the horizontal, the south pole being above the north pole in the northern hemisphere and the south pole being below the north pole in the southern hemisphere. It is 0° at the magnetic equator and 90° at the magnetic north and south poles of earth. At other places, it lies between 0° and 90°. At Delhi, it is 42° 12.7′. The angle of dip θ measured in the magnetic meridian is called the true angle of dip and the angle of dip θ′ measured in any other vertical plane inclined at an angle ϕ with the magnetic meridian is called the apparent angle of dip. The 'Dip Circle' is used to measure the angle of dip in any vertical plane.

$$\tan\theta = \frac{B_V}{B_H},$$

$$\tan\theta' = \frac{B_V}{B_H'} = \frac{B_V}{B_H\cos\phi}$$

$$\Rightarrow \quad \tan\theta' = \left(\frac{1}{\cos\phi}\right)\tan\theta$$

$$\Rightarrow \quad \theta' > \theta$$

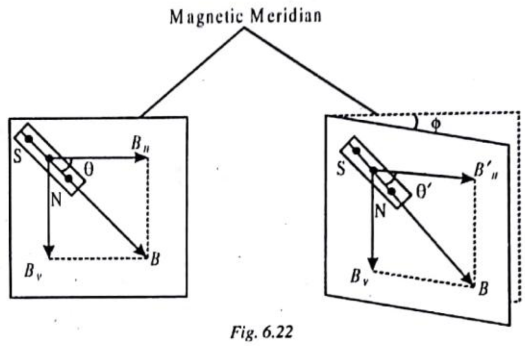

Fig. 6.22

Variation, or Declination, α

At a place, the angle α between the magnetic and geographic meridians is called the variation, or declination. It is 0° at Delhi.

Magnetic Elements of Earth

The three parameters, namely, the angle of dip or inclination θ, variation or declination α and horizontal component B_H of earth's magnetic field $\vec{B}$, are together called the magnetic elements of earth. These elements completely define the earth's magnetism.

Magnetic Compass:

Present day magnetic compasses use the same forces that guided ancient mariners. A magnetized needle, in conjunction with a compass card, rotates horizontally. Present day compasses are superior to the ancient ones through a heightened knowledge of magnetic laws and greater precision in construction.

The Earth's magnetic lines of force provide the directional information needed to navigate. A compass detects and converts the energy from these magnetic lines of force into a directional display. In order to understand the operation of a ship's compass, it is first necessary to understand some basic information about the Earth's magnetic field.

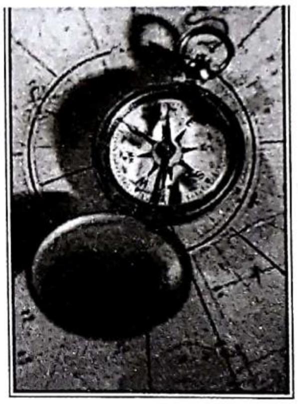

Fig. 6.23

Magnetism in medicine

An electric current always produces a magnetic field. Even weak ion currents that travel along the nerve cells in our body produce magnetic fields. When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a temporary magnetic field. These fields are very weak and are about one-billionth of the earth's magnetic field. Two main organs in the human body where the magnetic field produced is significant, are the heart and the brain. The magnetic field inside the body forms the basis of obtaining the images of different body parts. This is done using a technique called Magnetic Resonance Imaging (MRI). Analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine.

FACT

In research and industry, MRI is known as NMR – Nuclear Magnetic Resonance. It's more or less the same process, but the medical establishment prefers the term MRI because some patients are scared off by the word nuclear.

The first MRI on a human was made in July 1977 by Dr. Raymond Damadian of New York. MRI patients are sometimes injected with gadolinium, a contrast agent that can make abnormalities such as tumors clearer due to the element's special magnetic properties.

MRIs are most commonly used for cancer patients (about 35 percent of all scans) and patients with spinal problems (about 30%).

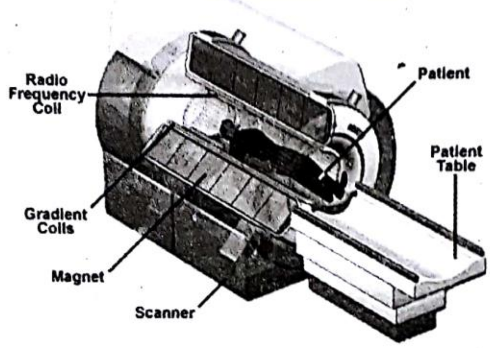

Fig. 6.24

NEUTRAL POINTS

Points where net magnetic field is zero are called neutral points.

Magnet in Horizontal Position

When a magnet is placed in the horizontal position with it's north pole facing the north, we get the two neutral points P_1 and P_2 on the equator of magnet, symmetrically placed with respect to the magnet, as shown. At the neutral points, the earth's horizontal component $\vec{B}_H$ and the magnetic field $\vec{B}$ of magnet balance each other so that the resultant magnetic field is zero there. Therefore,

$$B_H = B = \left(\frac{\mu}{4\pi}\right)\frac{M}{(r^2+l^2)^{3/2}}$$

$$\approx \left(\frac{\mu}{4\pi}\right)\frac{M}{r^3} \text{ for } l << r$$

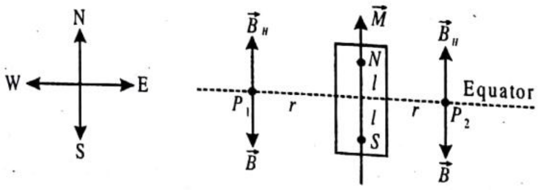

Fig. 6.25

When the magnet is placed in the horizontal position with it's north pole facing the south, we get the two neutral points P_1 and P_2 on the axis of magnet, symmetrically placed with respect to the magnet, as shown. At the neutral points, we have

$$B_H = B = \left(\frac{\mu}{4\pi}\right)\frac{2Mr}{(r^2-l^2)^2}$$

$$\approx \left(\frac{\mu}{4\pi}\right)\frac{2M}{r^3} \text{ for } l << r$$

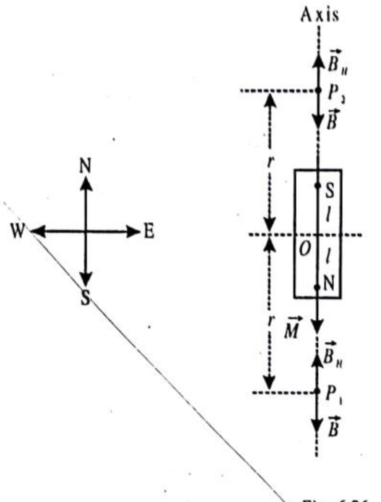

Fig. 6.26

Magnet in Vertical Position

When the magnet is placed in the vertical position with it's north pole resting on the table, we get only one neutral point P on the south of magnet in the plane of the table top, as shown. At the neutral point we have

$B_H = B = B_N - B_S \cos\theta$ (for short magnet)

$\approx B_N$ (for long magnet, i.e., $l >> r$)

where,

$$B_N = \left(\frac{\mu}{4\pi}\right)\frac{m}{r^2}$$

$$B_S = \left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2 + 4l^2)}$$

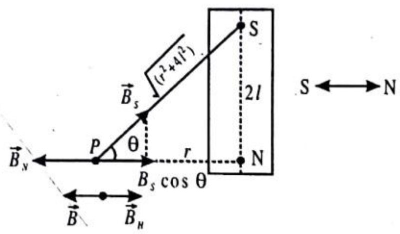

Fig. 6.27

are the magnetic fields due to the two poles, taken separately.

When the magnet is placed in the vertical position with it's south pole resting on the table, we get only one neutral point P on the north of magnet in the plane of the table top, as shown. At the neutral point, we have

$B_H = B = B_S - B_N \cos\theta$ (for short magnet)

$\cong B_S$ (for long magnet, i.e., $l >> r$)

where $$B_N = \left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2 + 4l^2)}$$

$$B_S = \left(\frac{\mu}{4\pi}\right)\frac{m}{r^2}$$

are the magnetic fields due to the two poles.

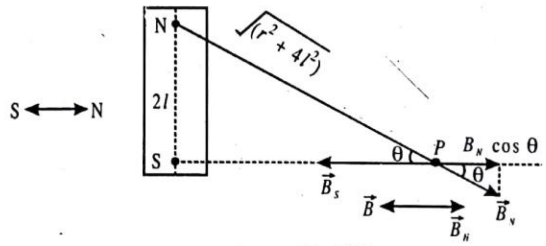

Fig. 6.28

CHECK Point

- **Magnet A has twice the magnetic field strength of magnet B, and, at a certain distance, it pulls on magnet B with a force of 50 N. With how much force, then, does magnet B pull on magnet A ?**

SOLUTION

The magnet B will pull on magnet A with the same force as magnet A pulls on magnet B, i.e, with a force of 50 N only because the force of attraction between the two magnets is a combined property of both the magnets and acts equally on both.

ILLUSTRATION – 6.3

A bar magnet of the length of 0.2 m is placed horizontally with it's *S*-pole towards the geographic north. The two neutral points are situated on the axis of magnet at the distance of 0.4 m from the centre of magnet. If the horizontal component of earth's magnetic field is $B_H = 3.2 \times 10^{-5}$ T, then find the pole strength of magnet.

SOLUTION:

The two neutral points are situated in the end-on positions on the axis of magnet such that the magnetic field B of magnet and earth's horizontal component B_H are equal but opposite and hence, cancel out each other exactly. Thus

$$B = B_H$$

$$\Rightarrow \quad \left(\frac{\mu_0}{4\pi}\right)\frac{2Mr}{(r^2 - l^2)^2} = B_H$$

$$\Rightarrow \quad (10^{-7})\frac{2 \times 2ml \times r}{(r^2 - l^2)^2} = B_H$$

$$\Rightarrow \quad (10^{-7})\frac{2 \times 2 \times m \times 0.1 \times 0.4}{[(0.4)^2 - (0.1)^2]^2} = 3.2 \times 10^{-5}$$

$$\Rightarrow \quad m = 45 \text{ Am}$$

MAGNETIC MATERIALS

Certain materials, when placed in a magnetising field $\vec{B}_0$, i.e., in a magnetising field intensity $\vec{H} = \vec{B}_0 / \mu_0$, get magnetised. Such materials are called the magnetic materials. Some materials get magnetised very strongly, e.g., ferromagnetics and others get magnetised very feebly, e.g., diamagnetics and paramagnetics.

TERMS RELATED TO MAGNETISM

Magnetic intensity ($\vec{H}$) : When a magnetic material is placed in a magnetic field, it becomes magnetised. The capability of the magnetic field to magnetise a material is expressed by means of a magnetic vector $\vec{H}$, called the 'magnetic intensity' of the field. The relation between magnetic induction B and magnetising field $\vec{H}$ is $\vec{B} = \mu\vec{H}$, μ being permeability of medium.

Intensity of magnetisation (I) : When a material is placed in a magnetising field, it acquires magnetic moment M. The intensity of magnetisation is defined as the magnetic moment per unit volume i.e., $I_m = \frac{M}{V}$, V being volume of mateiral. If the material is in the form of a bar of cross-sectional area A, length 2l and pole strength m, then

$$M = m \times 2\ell;\ V = A \times 2\ell \qquad \therefore\ I_m = \frac{M}{V} = \frac{m.2\ell}{A.2\ell} = \frac{m}{A}$$

Magnetic Susceptibility (χ) : The magnetic susceptibility is defined as the intensity of magnetisation per unit magentising field i.e.,

$$\chi = \frac{I_m}{H}.$$

Magnetic permeability (μ) : The magnetic permeability of a material is the measure of degree to which the material can be permeated by a magnetic field and is defined as the ratio of magnetic induction (B) in the material to the magnetising field i.e.

$$\mu = \frac{B}{H}$$

RELATION BETWEEN MAGNETIC SUSCEPTIBILITY AND PERMEABILITY

We have magnetic induction in mateiral, $B = \mu H$

Also $B = B_0 + B_m$

where B_0 = magnetic induction in vacuum produced by magnetising field

B_m = magnetic induction due to magnetisation of material.

But $B_0 = \mu_0 H$ and $B_m = \mu_0 I_m \Rightarrow B = \mu_0[H + I_m]$

$\therefore\ B = \mu_0 H\left[1 + \frac{I_m}{H}\right] = B_0\,[1 + \chi]$; $\therefore\ B/B_0 = [1 + \chi]$ $\therefore\ B/B_0 = \frac{\mu H}{\mu_0 H} = \mu/\mu_0$, the relative magnetic permeability

$$\therefore\ \mu_r = 1 + \chi$$

This is required relation.

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CLASSIFICATION OF MATERIALS

According to the behaviour of substances in magnetic field, they are classified into three categories

(I) DIAMAGNETIC SUBSTANCES. These are substances which when placed in a strong magnetic field acquire a feeble magnetism opposite to the direction of magnetising field.

The examples are copper gold, antimony, bismuth, alcohol, water, quartz, hydrogen, etc.

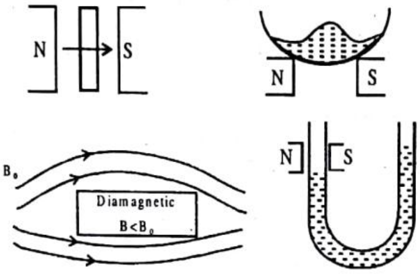

Fig. 6.29 : Behaviour of Diamagnetic substance in an external Magnetic field $\vec{B}_0$

The characteristics of diamagnetic substances are

(a) They are feebly repelled by a strong magnet

(b) Their susceptibility is negative (i.e. $\chi < 0$)

(c) Their relative permeability is less than 1. (i.e. $\mu_r < 1$)

(d) Their susceptibility is independent of magnetising field and temperature (except for Bismuth at low temperature).

(II) PARAMAGNETIC SUBSTANCES. These are the materials which when placed in a strong magnetic field acquire a feeble magnetism in the same sense as the applied magnetic field. The examples are platinum, aluminium, chromium, manganese, $CuSO_4$, O_2, air, etc.

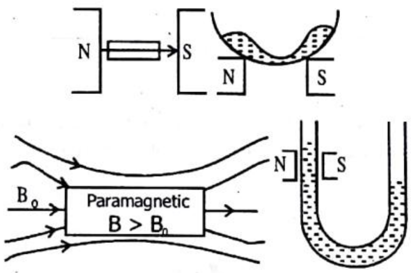

Fig. 6.30 : Behaviour of Paramagnetic substance in an external field $\vec{B}_0$

The characteristics of paramagnetic substances are

(a) They are attracted by a strong magnet

(b) Their susceptibility is positive but very small ($\chi > 0$)

(c) Their relative permeability is slightly greater than unity. ($\mu > 1$)

(d) Their susceptibility and permeability do not change with the variation of magnetising field.

(e) Their susceptibility is inversely proportional to temperature, $\left(\text{i.e. } \chi \alpha \frac{1}{T}\right)$

(f) Found in those material which have atoms containing odd number of electrons

(III) FERROMAGNETIC SUBSTANCES. These are the substances which are strongly magnetised by relatively weak magnetising field in the same sense as the magnetising field. The examples are Ni, Co, iron and their alloys.

The characteristics of ferromagnetic substances are :

(a) They are attracted even by a weak magnet.

(b) The susceptibility is very large and positive. ($\chi >> 0$)

(c) The relative permeability is very high (of the order of hundreds and thousands). ($\mu >> 1$)

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(d) The intensity of magnetisation is proportional to the magnetising field H for smaller values, varies rapidly for moderate values and attains a constant value for larger values of H.

(e) The susceptibility of a ferromagnetic substance is inversely proportional to temperature i.e.,

$\chi \propto 1/T \Rightarrow \chi = \frac{C}{T}$; C = curie constant.

This is called Curie law. At a temperature called **curie temperature**, ferromagnetic substance becomes paramagnetic. The curie temperatures for Ni, Fe and Co are 360°C, 740°C and 1100°C respectively.

(f) Found in those material which have domains and can be converted into strong magnets

Keep in memory

1. Diamagnetism is universal. It is present in all materials. But it is weak and hard to detect if substance is para or feromagnetic
2. I.– H curve for different materials

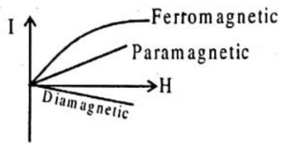

Fig. 6.31

3. Curve for magnetic susceptibility and temperature for a paramagnetic and ferromagnetic material.

$\chi \propto \frac{1}{T}$

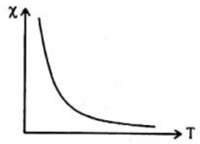

Fig. 6.32

HYSTERESIS

When a bar of ferromagnetic material is magnetised by a varying magnetic field and the intensity of magnetisation I_m induced is measured for different values of magnetising field H, the graph of I versus H is as shown is fig. The graph shows

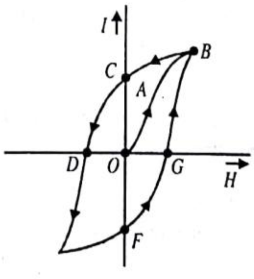

Fig. 6.33

(i) When magnetising field is increased from O the intensity of magnetisation I_m increases and becomes maximum (i.e. point A). This maximum value is called the **saturation value.**

(ii) When H is reduced, I_m reduces but is not zero when H = 0. The remainder value OB of magnetisation when H = 0 is called the residual magnetism or **retentivity**. OB is retentivity.

(iii) When magnetic field H is reversed, the magnetisaiton decreases and for a particular value of H, it becomes zero i.e., for H = OC, I = 0. This value of H is called the **coercivity**.

(iv) When field H is further increased in reverse direction, the intensity of magnetisation attains saturation value in reverse direction (i.e., point D).

(v) When H is decreased to zero and changed direction in steps, we get the part DFGA.

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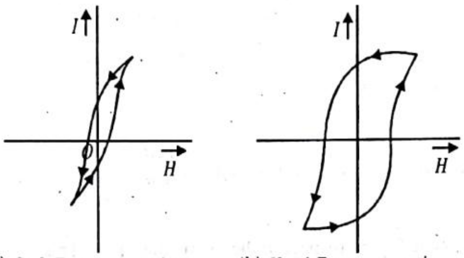
Properties of soft iron and steel

For soft iron, the susceptibility, permeability and retentivity are greater while coercivity and hysteresis loss per cycle are smaller than those of steel.



(a) Soft Ferromagnetics (b) Hard Ferromagnetics

Fig. 6.34

Permanent magnets are made of steel and cobalt while electromagnets are made of soft iron.

Oersted's Experiment : An evidence of magnetic effect of current

After the invention of electric batteries, electric currents were a hot scientific topic, but no one suspected they had anything to do with magnetism. A Danish professor, Hans Christian Oersted, prepared for some friends, a science demonstration in his home. It included the heating of a wire by an electric current from a battery, and also some demonstrations of magnetism, using a compass on a stand.While carrying out the heating experiment, Oersted noted that every time he connected the current, the compass needle moved, too, something completely unexpected. No one else took notice. In the four months that followed he tried hard to make sense of the phenomenon; but he couldn't. The compass needle was neither attracted nor repelled, but tended to stand perpendicular to the wire.

Following Oersted's article, the effect was confirmed by Andre-Marie Ampere, he felt that if a current in a wire exerted a magnetic force on a compass needle, two such wires also should interact magnetically. In a series of ingenious experiments he showed that this interaction was simple and fundamental, parallel (straight) currents attract, anti-parallel currents repel. The force between two long straight parallel currents was inversely proportional to the distance between them and proportional to the intensity of the current flowing in each. Loops of current attract or repel like magnets, coils with many loops multiplied the magnetic force, and Ampere guessed that iron atoms were magnetic because electric currents (soon named "Ampere currents") circulated in them.

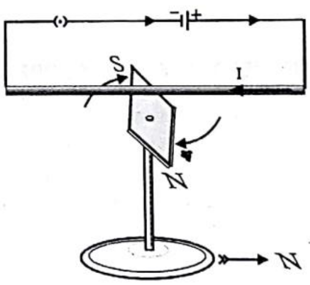


Fig. 6.35: Oersted's experiment. Current in the wire deflects the compass needle.

CHECK Point

- **In figure, we see a magnet exerting a force on a current-carrying wire. Does a current-carrying wire exert a force on a magnet ? Why or why n**

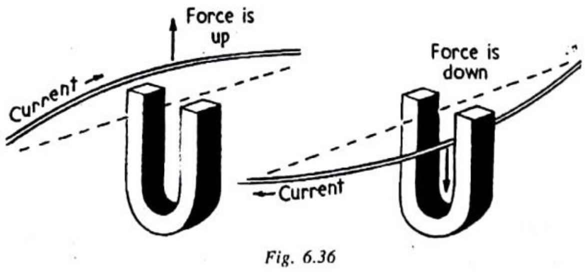


Fig. 6.36

SOLUTION

Yes, a current-carrying wire also exert a force on a magnet. The current-carrying wire produces a magnetic field around it. When a magnet is brought near the wire, its magnetic field interacts with the magnetic field created by the wire. Due to this interaction the magnet experiences a force.

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BIOT-SAVART LAW

The Biot-Savart Law defines the magnetic field $\vec{B}$ due to a current distribution in terms of the distribution. For example, let us consider a line distribution of steady current I confined to a filamentary wire ST. The wire may be imagined to be subdivided into the many elementary parts, each characterised by a vector $d\vec{l}$ whose magnitude is equal to the length of elementary part and whose direction is that of the current, as shown.

The magnetic field at a point P due to an elementary part is $d\vec{B} = \left(\frac{\mu_0 I}{4\pi}\right)\left(\frac{d\vec{l}\times\vec{R}}{R^3}\right)$

where $\vec{R}$ is the position vector of point P with respect to the elementary part. This magnetic field has the magnitude

$$dB = \left(\frac{\mu_0 I}{4\pi}\right)\left(\frac{dl\sin\theta}{R^2}\right)$$

and the direction of the cross product $(d\vec{l}\times\vec{R})$, i.e., inwards and perpendicular to the plane of figure, as shown. The magnetic field $\vec{B}$ at the point P due to the complete wire ST is obtained by performing a summation process over all the elementary parts. The direction of $\vec{B}$ will be the same as that of an elementary magnetic field $d\vec{B}$.

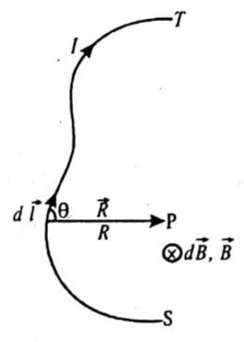

Fig. 6.37

MAGNETIC FIELD DUE TO A CURRENT CARRYING CONDUCTOR

From Oersted experiment followed by Ampere we can conclude that a magnetic field is developed around a conductor when electric current is passed through it. This observation is called magnetic effect of electric current. The presence of a current in a wire near a magnetic compass affected the direction of the compass needle. We now know that current gives rise to magnetic fields, just as electric charge give rise to electric fields.

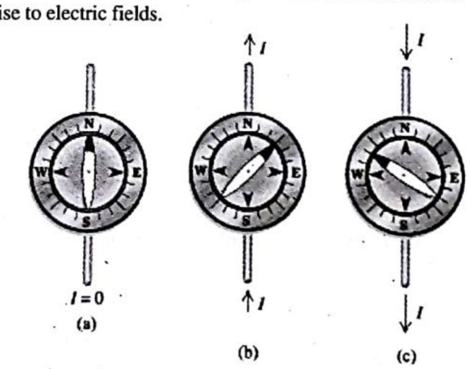

Fig. 6.38 : Compass near a current-carrying wire

Straight conductor

The magnetic field around a conductor carrying current is in the form of closed circular loops, in a plane perpendicular to the conductor, and is given by right hand thumb rule.

Right hand thumb rule. If we grasp the conductor in the palm of the right hand so that the thumb points in the direction of the flow of current, then the direction in which the fingers curl, gives the direction of magnetic field lines.

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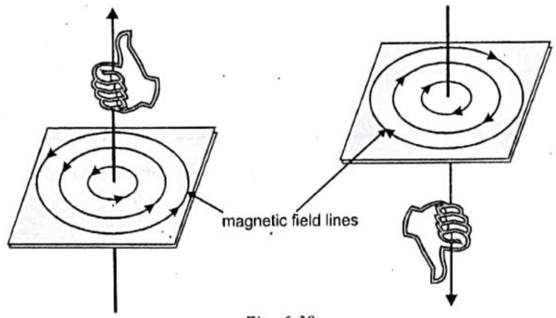

(a) *Fig. 6.39* (b)

For the current flowing through the conductor in the direction shown in figures (a) or (b), the rule predict that magnetic field lines will be in anticlockwise direction, when seen from above.
This rule is also called Maxwell's corkscrew rule. If we consider ourselves driving a corkscrew in the direction of the current, then the direction of the corkscrew is the direction of the magnetic field.

Ampere's swimming rule

Imagine a man swimming along the wire, in the direction of current, (such that the current enters at his feet and leaves him at his head) and facing towards a compass needle placed underneath the wire, then the magnetic field produced is such that the north pole of the compass needle gets deflected towards his left hand.

Knowledge ENHANCER

Magnetic field due to long straight conductor

$B = \frac{\mu_0 I}{4\pi r}(\sin\theta_1 + \sin\theta_2)$ $\qquad \frac{\mu_0}{4\pi} = 10^{-7}\frac{\text{Tesla}-m}{\text{Amp.}}$

If the conductor is infinitely long, then $\theta_1 = 90°$ *and* $\theta_2 = 90°$

$$B = \frac{\mu_0 I}{4\pi r}\left[\sin\frac{\pi}{2} + \sin\left(\frac{\pi}{2}\right)\right] = \frac{\mu_0 I}{4\pi r}[1+1]\frac{\mu_0}{4\pi}\frac{2I}{r}$$

or $B = \frac{\mu_0 I}{2\pi r}$

If conductor is of infinite length but one end is in front of point P i.e. one end of conductor starts from point N then

$\theta_1 = 0°$ *and* $\theta_2 = 90°$ $B = \frac{\mu_0 I}{4\pi r}$

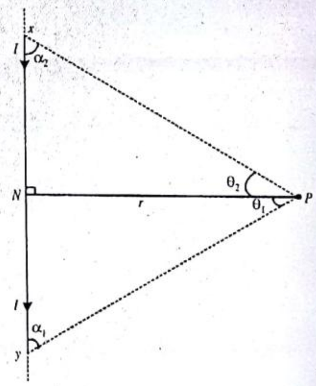

Fig. 6.40

Conductor is finite length and point P is just in front of middle of the conductor

$B = \frac{\mu_0 I}{4\pi r}(2\sin\theta)$ $\qquad [\theta_1 = \theta_2 = \theta]$

$B = \frac{\mu_0 I L}{2\pi r\sqrt{L^2 + r^2}}$ $\qquad \sin\theta = \frac{L/2}{\sqrt{\left(\frac{L}{2}\right)^2 + r^2}}$

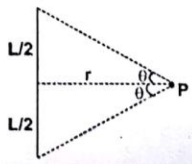

Fig. 6.41

CHECK Point

- **A beam of high-energy protons emerges from a cyclotron. Do you suppose there is a magnetic field associated with these particles? Why or why not?**

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SOLUTION

Yes. I suppose there is a magnetic field associated with these particles. The particles are moving charged particles which produce a magnetic field.

ILLUSTRATION 6.4

Compute the magnetic field at a point of 9 cm from the long straight wire carrying a current of 6A.

SOLUTION :

$a = 9\text{ cm} = 9 \times 10^{-2}\,m, I = 6A$

$$B = \frac{\mu_o I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 6}{2\pi \times 9 \times 10^{-2}} = 1.33 \times 10^{-5}\text{T}$$

CIRCULAR LOOP

At every point of a current-carrying circular loop, the concentric circles representing the magnetic field around it would become larger and larger as we move away from the wire (**Fig.6.42**). By the time we reach at the centre of the circular loop, the arcs of these big circles would appear as straight lines. Every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the center of the loop. By applying the right hand rule, it is easy to check that every section of the wire contributes to the magnetic field lines in the same direction within the loop.

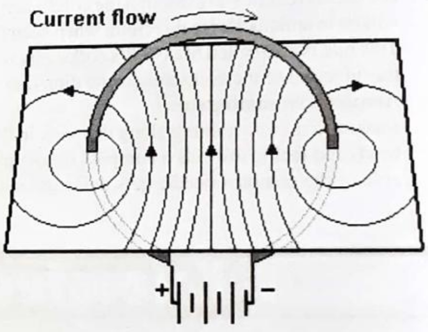

Fig. 6.42

Knowledge ENHANCER

Magnetic field at the centre of a circular current-carrying coil

$$B = \frac{\mu_0 I}{2r}$$

For a coil of n turns, $B = \frac{\mu_0 n I}{2r}$

Magnetic Field due to part of current carrying circular conductor (Arc)

$$B = \frac{\mu_0 I}{4\pi r}\alpha$$

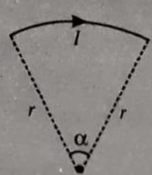

Fig. 6.43

Magnetic field on the axis of a circular coil

$$B = \frac{\mu_0\, N\, I\, a^2}{2(a^2 + x^2)^{3/2}}$$

At the centre of the loop, x = 0

$$B = \frac{\mu_0\, N\, I\, a^2}{2\, a^3} \quad \text{or} \quad B = \frac{\mu_0\, N\, I}{2\, a}$$

In terms of area A (= πa²) of the circular current loop, the quantity N I A is known as the magnetic dipole moment M of the current loop.

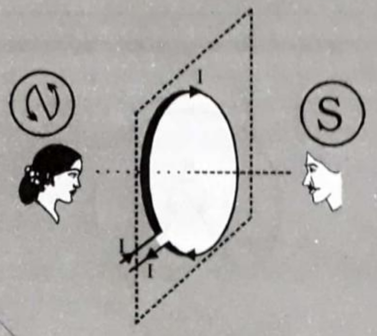

Fig. 6.44

Magnetic dipole moment of the current loop

The current loop can be regarded as a magnetic dipole which produces its magnetic field and magnetic dipole moment of the current loop is equal to the product of ampere turns and area of current loop, we can write

$$B = \frac{\mu_0 N I A}{2r(\pi a^2)} = \frac{\mu_0}{2\pi}\frac{NIA}{a^3} \quad or \quad B = \frac{\mu_0}{4\pi}\frac{2NIA}{a^3} \quad \therefore \quad B = \frac{\mu_0}{4\pi}\frac{2M}{a^3}$$

If the observation point is far away from the coil, then a << x. So, a^2 can be neglected in comparison to x^2.

$$\therefore \quad B = \frac{\mu_0 N I a^2}{2x^3}$$

In terms of magnetic dipole moment, $B = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$ $\left[B = \frac{\mu_0}{2\pi}\frac{NIA}{x^3} = \frac{\mu_0}{4\pi}\frac{2NIA}{x^3}\right]$

RIGHT HAND PALM RULE. If we hold the thumb of right hand mutually perpendicular to the grip of the fingers such that the curvature of the finger represents the direction of current in the wire loop, then the thumb of the right hand will point in the direction of magnetic field near the centre of the current loop.

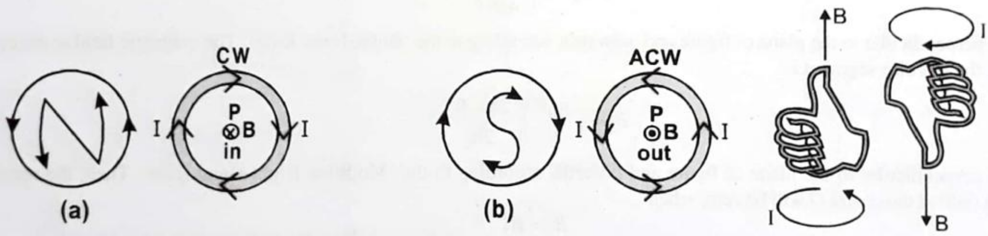

Fig. 6.45

ILLUSTRATION 6.5

An infinite straight conductor carrying current $2I$ is split into a loop of radius r as shown in figure. The magnetic field at the centre of the coil is

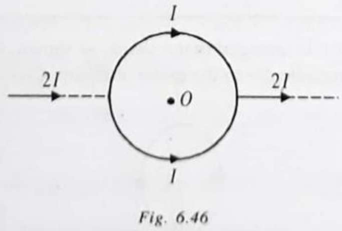

Fig. 6.46

SOLUTION:

Here, the wire does not produce any magnetic field at O because the conductor lies on the line of O. Also, the loop does not produce magnetic field at O.

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ILLUSTRATION 6.6

A current of I ampere flows in a wire forming a circular arc of radius r metres subtending an angle θ at the centre as shown. The magnetic field at the centre O in tesla is

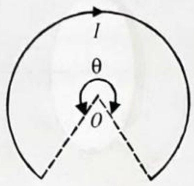

Fig. 6.47

SOLUTION:

$$B = \frac{\mu_0 I}{2r} \times \frac{\theta}{2\pi} = \frac{\mu_0 I\theta}{4\pi r}$$

ILLUSTRATION 6.7

A conducting wire of infinite length, carrying a current I, is arranged in the shape, as shown. If the magnetic field at the centre O of circular segment is zero, then, calculate the angle θ.

Fig. 6.48

SOLUTION:

The magnetic field at the centre O due to the two straight segments, taken together, is

$$B_1 = 2\left(\frac{\mu_0 I}{4\pi}\right)$$

which is perpendicular to the plane of figure and outwards, according to the 'Right-Hand Rule'. The magnetic field at the centre O due to the circular segment is

$$B_2 = \left(\frac{\mu_0 I}{2r}\right)\left(\frac{2\pi - \theta}{2\pi}\right)$$

which is perpendicular to the plane of figure and inwards, according to the 'Modified Right-Hand Rule'. Then, the resultant magnetic field at the centre O will be zero, when

$$B_1 = B_2$$

$$\Rightarrow \quad 2\left(\frac{\mu_0 I}{4\pi r}\right) = \left(\frac{\mu_0 I}{2r}\right)\left(\frac{2\pi - \theta}{2\pi}\right)$$

$$\Rightarrow \quad \theta = 2(\pi - 1)$$

ILLUSTRATION 6.8

A long conducting wire, carrying a current I, is arranged in the shape, as shown, with the two straight segments in the plane of figure and the circular loop of radius r perpendicular to the plane of figure. Calculate the magnetic field at the centre O of the circular loop.

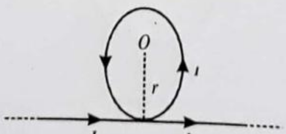

Fig. 6.49

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SOLUTION :

The magnetic field at the centre O of the circular loop due to the two straight segments, taken together, will be

$$B_1 = 2\left(\frac{\mu_0 I}{4\pi r}\right)$$

which is perpendicular to the plane of figure and outwards, according to the 'Right-Hand Rule'. The magnetic field at the centre O due to the circular loop will be

$$B_2 = \left(\frac{\mu_0 I}{2r}\right)$$

which is parallel to the straight segments and towards right. Since, the two magnetic fields B_1, B_2 are mutually perpendicular, the resultant magnetic field at the centre O is given by

$$B = \sqrt{B_1^2 + B_2^2} = \left(\frac{\mu_0 I}{2r}\right)\sqrt{\left(\frac{1}{\pi^2}+1\right)}$$

FORCE ON A CHARGED PARTICLE IN A MAGNETIC FIELD

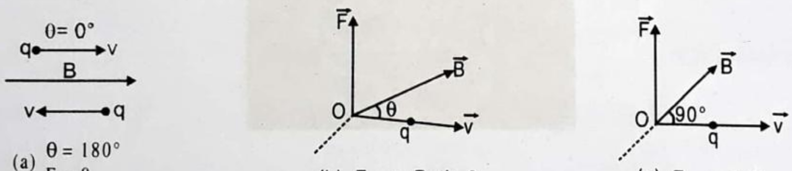
According to Lorentz , charge particle q moving with velocity v in a magnetic field B experiences

Force, $\vec{F} = q\,(\vec{v}\times\vec{B})$

The force $\vec{F}$ is always perpendicular to both the velocity $\vec{v}$ and the field $\vec{B}$.
A charged particle at rest in a steady magnetic field does not experience any force.

If the charged particle is at rest then $\vec{v} = 0$, so $\vec{v} \times \vec{B} = 0$
A moving charged particle does not experience any force in a magnetic field if its motion is parallel or antiparallel to the field.
i.e., if $\theta = 0°$ or $180°$,

then, $|\vec{F}| = q\,v\,B\sin\theta = 0$ $[\because \sin 0° = 0 \text{ and } \sin 180° = 0]$



(a) $\theta = 180°$, $F = 0$ (b) $F = qvB\sin\theta$ (c) $F_{max} = qvB$

Fig. 6.50

If the particle is moving perpendicular to the field.

In this situation all the three vectors $\vec{F}$, $\vec{v}$ and $\vec{B}$ are mutually perpendicular to each other.
Then $\sin\theta = \max = 1$, i.e., $\theta = 90°$,
The force will be maximum $F_{max} = q\,v\,B$
Work done by force due to magnetic field in motion of a charged particle is always zero.
When a charged particle move in a magnetic field, then force acts on it is always perpendicular to displacement,

so the work done, $W = \vec{F}.\vec{s} = Fs\cos\theta = 0$ (as $\theta = 90°$),

And as by work-energy theorem $W = \Delta$ KE, the kinetic energy ($= \frac{1}{2}mv^2$) remains unchanged and hence speed of charged particle v remains constant.
However, in this situation the force changes the direction of motion, so the direction of velocity $\vec{v}$ of the charged particle changes continuously.
The direction of the cross product can be obtained by using a right-hand rule:
Fingers of the right hand point in the direction of the first vector (v) in the cross product, then adjust your wrist so that you can bend your fingers (at the knuckles) toward the direction of the second vector (B); extend the thumb to get the direction of the force.

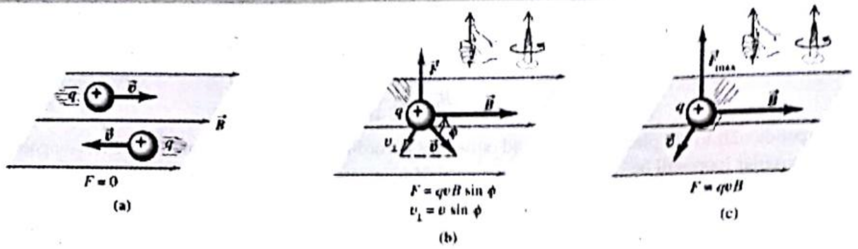


Fig. 6.51 : Magnetic force acting on a moving charge.

A charged particle moving in a plane perpendicular to a magnetic field will move in a circular orbit with the magnetic force playing the role of centripetal force. The direction of the force is given by the right-hand rule. Equating the centripetal force with the magnetic force and solving for R the radius of the circular path we get, $mv^2 / R = q\,v\,B$ and $R = m\,v / q\,B$

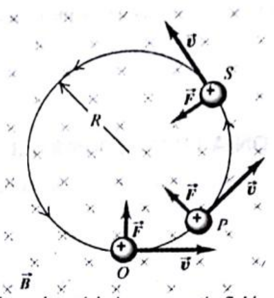


Fig. 6.52 : Orbit of charged particle in a magnetic field.

If charge particle projected at some angle with magnetic field it will move on helical path as shown.

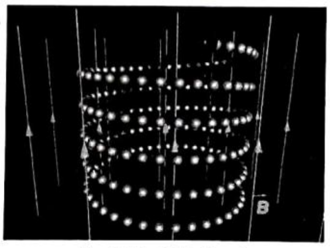


Fig. 6.53 : Helical path.

ILLUSTRATION 6.9

A magnetic field of $(4.0\times10^{-3}\,\hat{k})\,T$ exerts a force of $(4.0\,\hat{i}+3.0\,\hat{j}\times10^{-10})$ N on a particle, having a charge of 1.0×10^{-9} C and moving in the x - y plane. Find the velocity of particle.

SOLUTION :

As the particle is moving in the x - y plane, it's velocity can be expressed as $\vec{v} = (v_x\,\hat{i} + v_y\,\hat{j})$ m/s. Then, the magnetic force on it becomes

$$\vec{F}_m = q(\vec{v}\times\vec{B})$$

$$= 1.0\times10^{-9}\left[(v_x\,\hat{i} + v_y\,\hat{j})\times(4.0\times10^{-3}\,\hat{k})\right]$$

$$= +4.0\times10^{-12}\,v_y\,\hat{i} - 4.0\times10^{-12}\,v_x\,\hat{j} \equiv (4.0\times\hat{i} + 3.0\,\hat{j})\,10^{-10}$$

Comparing the coefficients of unit vectors of both sides, we have

$$v_x = -75,\ v_y = +100$$

and then, the velocity of particle is given by

$$\vec{v} = (-75\,\hat{i} + 100\,\hat{j})\ \text{m/s}$$

ILLUSTRATION - 6.10

A charge of 2.0×10^{-6} C is moving with a speed of 2.0×10^{6} m/s in the + x direction in a magnetic field $\vec{B}=\left(0.2\,\hat{j}+0.4\hat{k}\right)T$. Find the magnetic force on the charge.

SOLUTION :

As the charge is moving with a speed of 2.0×10^{-6} m/s in the + x direction, it's velocity can be expressed as

$$\vec{v} = \left(2.0\times10^{6}\right)\hat{i} \text{ m/s}$$

and then, the magnetic force on the charge will be

$$\begin{aligned}\vec{F}_m &= q\left(\vec{v}\times\vec{B}\right)\\ &= 2.0\times10^{-6}\left[\left(2.0\times10^{6}\,\hat{i}\right)\times\left(0.2\,\hat{j}+0.4\,\hat{k}\right)\right]\\ &= 4.0\left[\hat{i}\times\left(0.2\,\hat{j}+0.4\,\hat{k}\right)\right]\\ &= 0.8\left(\hat{i}\times\hat{j}\right)+1.6\left(\hat{i}\times\hat{k}\right)\\ &= \left(-1.6\hat{j}+0.8\,\hat{k}\right)N\end{aligned}$$

Knowledge ENHANCER

VELOCITY SELECTOR :

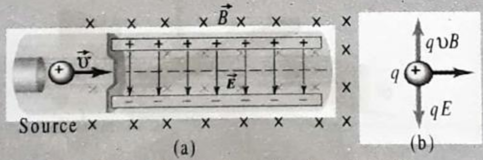


Fig. 6.65 : Velocity selector for charged particles

An electric field and a magnetic field placed at right angles to each other can function as a "velocity selector." When force up = force down, the charge will travel in a straight (horizontal) line. The speed can be obtained from the equation

q v B = q E, or v = E / B

Charged particles leaving a velocity selector (with a known velocity) can be inserted into a chamber with a magnetic field as shown. In the circular orbit equation above R = mv /q B. In the circular orbit equation above R = mv /q B.

We can substitute v = E / B to get R = m E / q B²
from which we can solve for m / v, the mass-to-charge ratio. Knowing the charge (ionized state) and the measured radius we can find the mass of the particle.

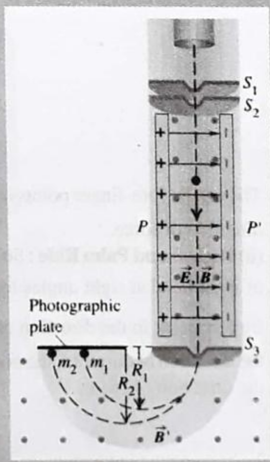


Fig. 6.54 : Mass spectrometer.

Force on a current carrying conductor in a magnetic field

Similar to the force on a moving charge in a B field, we have for a conductor of length L carrying a current of I in a B field the force experienced by the conductor : $\vec{F} = I\,\vec{L}\times\vec{B}$

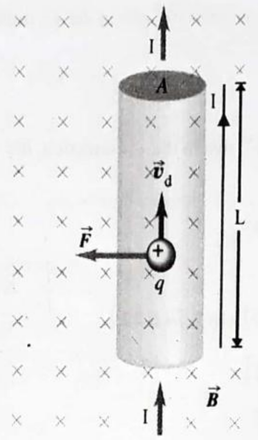


Fig. 6.55 : Force on a moving charge in a current-carrying conductor.

Direction of force can be determined by fleming's left hand rule, right hand palm rule or screw rule.

Fleming's Left-hand Rules

Stretch the fore-finger, central finger and thumb of left hand mutually perpendicular.

Fig. 6.56

Then if the fore-finger points in the direction of field $(\vec{B})$, the central finger in the direction of current I, the thumb will point in the direction of force.

(ii) Right-hand Palm Rule : Stretch the fingers and thumb of right hand at right angles to each other. Then if the fingers point in the direction of field $(\vec{B})$ and thumb in the direction of current I, the normal to palm will point in the direction of force.

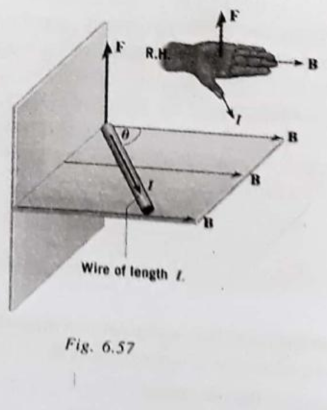


Fig. 6.57

To understand it in better manner see three figures.

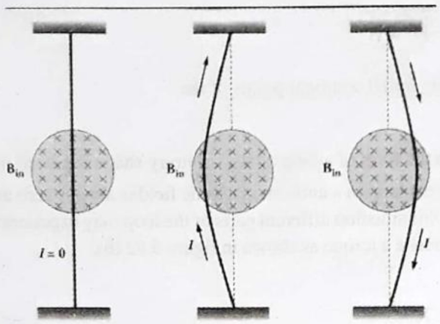


Fig. 6.58

If no current is flowing through the wire obviously the force will be zero, if current is flowing upward using right hand rule(field inward shown by ×) you will find force will act in left direction, hence wire will deflect as shown and if direction of current is downward force will try to move the wire in right direction and will deflect the wire as shown. **Screw rule :** Curl right hand finger from current towards magnetic field thumb will direction of force as shown in figure.

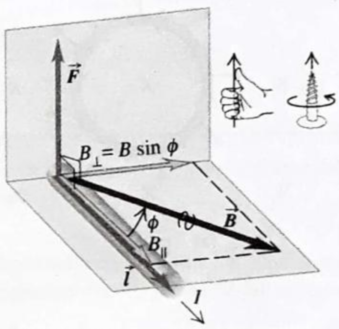


Fig. 6.59 : Magnetic force on straight wire segment.

You can see component of magnetic field perpendicular to current contributes in force on conductor. If current in wire is along external magnetic field force will be zero and if perpendicular to field it will be maximum.

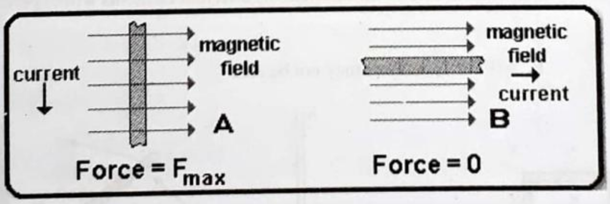


Fig. 6.60

If direction of current or field reverses direction of force also reverses as shown in figure 6.61

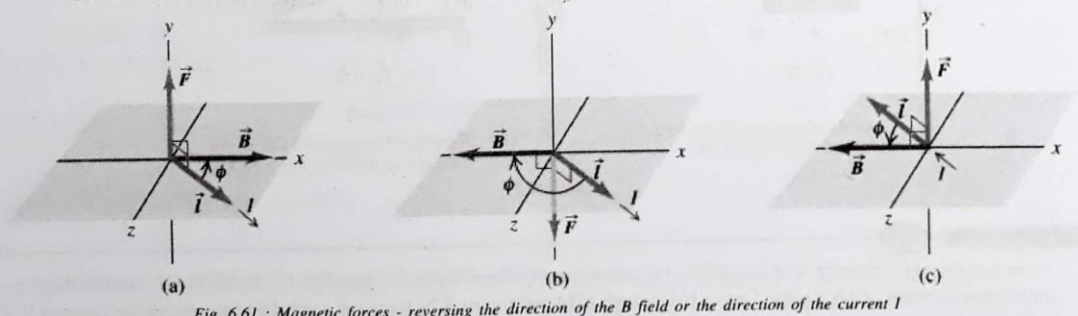


Fig. 6.61 : Magnetic forces - reversing the direction of the B field or the direction of the current I reverses the direction of the force.

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Ay arbitrary shape in a uniform field experience a force

$$\vec{F} = I\vec{\ell}' \times \vec{B}$$

where $\vec{\ell}'$ is the length vector joining initial and final points of the conductor as shown in figure.

If the current-carrying conductor in the form of a loop of any arbitrary shape is placed in a uniform field, then, $\vec{F} = 0$ i.e., the net magnetic force on a current loop in a uniform magnetic field is always zero as shown in figure 6.62 (a). Here it must be kept in mind that in this situation different parts of the loop may experience elemental force due to which the loop may be under tension or may experience a torque as shown in figure 6.62 (b).

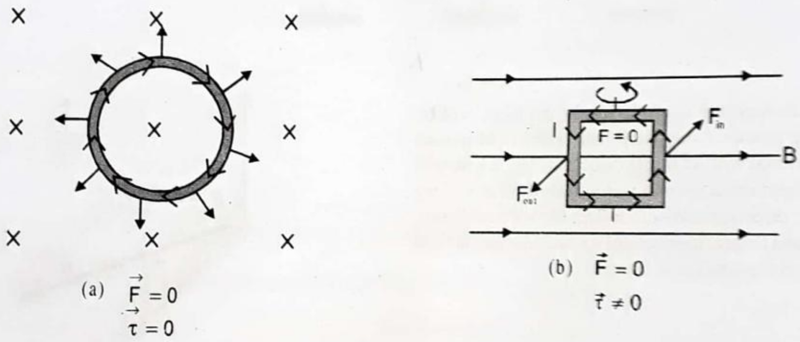
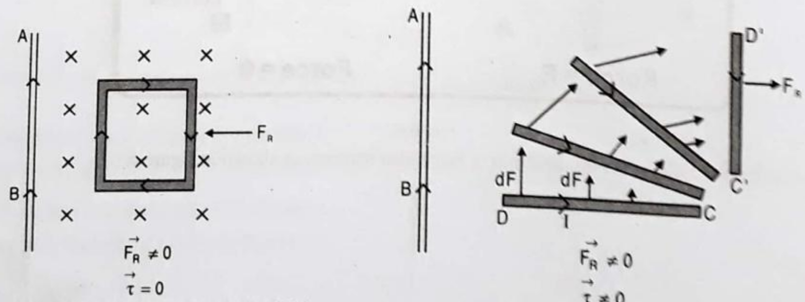


Fig. 6.62

CURRENT LOOP IN A UNIFORM FIELD

If a current-carrying conductor is situated in a non-uniform field, its different elements will experience different forces; so in this situation,

$$\vec{F}_R \neq 0 \text{ but } \vec{\tau} \text{ may or may not be zero}$$



(a) Current carrying loop in the field of current carrying wire AB

(b) A current carrying rod CD in the field of current carrying wire AB

Fig. 6.63

ILLUSTRATION–6.11

A vertical straight conductor X of length 0.5 m is situated in a uniform horizontal magnetic field, of 0.1T (i) calculate the force on X when a current of 4A is passed into it (ii) through what angle must X be turned in a vertical plane so that the force on X is halved ?

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SOLUTION:

(i) Here $L = 0.5\text{ m}, B = 0.1\text{T}, I = 4\text{A}, F = ?$

$F = BIL = 0.1 \times 4 \times 0.5 = 0.2\text{N}$

(ii) Let α be the required angle.

The force on the conductor

$$F' = \frac{1}{2}F\frac{0.2}{2} = 0.1\text{N}$$

$$F' = BIL\,\text{Sin}\theta$$

or $\frac{1}{2}\text{BIL} = \text{BILSin}(90° - \alpha)$

or $\frac{1}{2}\cos\alpha$ or $\alpha = \cos^{-1}\left(\frac{1}{2}\right) = 60°$

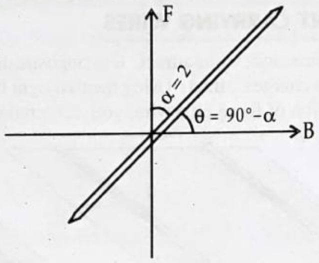


Fig. 6.64

ILLUSTRATION 6.12

A rectangular loop of sides 25 cm and 10 cm carrying a current of 15 A is placed with its longer side parallel to a long straight conductor 2.0 cm apart carrying a current of 25 A. What is the net force on the loop?

SOLUTION:

Consider a rectangular loop PQRS placed near a long straight conductor AB as shown in Figure 6.65. Due to the interaction of currents, the arm PQ of the loop will get attracted while arm RS will get repelled. Forces on the arms QR and SP will be equal and opposite and hence cancel out.

Here, $PQ = 25\text{ cm} = 25 \times 10^{-2}\text{ m}$,

$PS = 10\text{ cm} = 10 \times 10^{-2}\text{ m}$

Distance of PQ from AB,

$r_1 = 2.0\text{ cm} = 2.0 \times 10^{-2}\text{ m}$

Distance of RS from AB,

$r_2 = 2.0 + 10 = 12.0\text{ cm} = 12.0 \times 10^{-2}\text{ m}$

Current through long wire AB, $I_1 = 25$ A

Current through rectangular loop, $I_2 = 15$ A

$\therefore$ Force on the arm PQ, $F_1 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_1} \times \text{length } PQ$

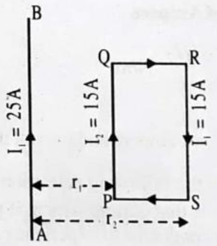


Fig. 6.65

$$F_1 = \frac{10^{-1} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{2.0 \times 10^{-2}}$$

$= 9.375 \times 10^{-4}$ (towards AB)

Force on the arm RS,

$$F_2 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_2} \times \text{length } RS = \frac{10^{-7} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{12 \times 10^{-2}}$$

$= 1.563 \times 10^{-4}$ (away from AB)

$\therefore$ Effective force on the loop,

$F = F_1 - F_2 = 9.375 \times 10^{-4} - 1.563 \times 10^{-4} = 7.812 \times 10^{4}$ N

(towards AB)

FORCE BETWEEN CURRENT CARRYING WIRES

If currents are in the same direction, wires attract. If in opposite direction, wires repel. This is the opposite of the rule for charges: like charges repel, opposite charges attract. Using the two right hand rules, one for finding the direction of the B-field of a wire, and the other for the direction of force on a wire, you can predict the results.

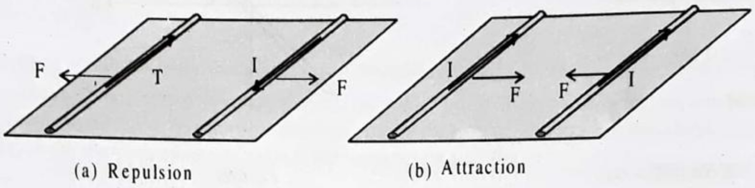


Fig. 6.66

The force per unit length on one wire due to other wire

$$\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi d}$$ [Where I_1, I_2 current in two wires and d = distance between wire]

Experimental Demonstration

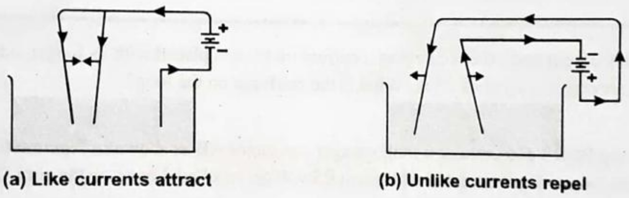


Fig. 6.67

Definition of Ampere

$$\because \quad F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r} \text{ N/m}$$

When $I_1 = I_2 = 1$ ampere and r = 1m, then $F = \frac{\mu_0}{2\pi} = \frac{4\pi\times10^{-7}}{2\pi}$ N/m $= 2\times10^{-7}$ N/m

This leads to the following definition of ampere.

One ampere is that current which, if passed in each of two parallel conductors of infinite length and one metre apart in vacuum causes each conductor to experience a force of 2×10^{-7} newton per metre of length of conductor.

ILLUSTRATION 6.13

Calculate the magnetic force per unit length experienced by a long straight wire W_1 carrying a current of 2A and placed parallel to and exactly midway between the two long, straight, and parallel wires W_2 and W_3 carrying the currents of 2A and 4A, respectively, in the opposite directions and separated by 0.1m.

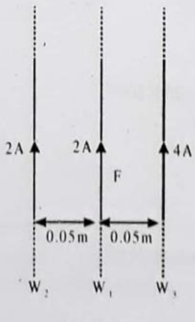


Fig. 6.68

SOLUTION :

The wire W_1 experiences an attractive magnetic force F_{12} per unit lenght towards left due to the wire W_2, carrying the parallel current. $$F_{12} = \frac{\mu_0 \times 2 \times 2 \times 1}{2\pi \times 0.05} = 1.6 \times 10^{-5}\ Nm^{-1}$$

The wire W_1 also experiences a repulsive magnetic force F_{13} per unit length towards left due to the wire W_3, carrying the antiparallel current. $$F_{13} = \frac{\mu_0 \times 2 \times 4 \times 1}{2\pi \times 0.05} = 3.2 \times 10^{-5}\ Nm^{-1}$$

Since, both magnetic forces on the wire W_1 are in the same direction towards left, the resultant magnetic force per unit length on it becomes

$$F = F_{12} + F_{13} = 4.8 \times 10^{-5}\ Nm^{-1}$$

ELECTROMAGNET

A magnetic field is produced when an electric current flows through a coil of wire. This is the basis of the electromagnet. We can make an electromagnet stronger by doing these things:

- wrapping the coil around an iron core
- adding more turns to the coil
- increasing the current flowing through the coil.

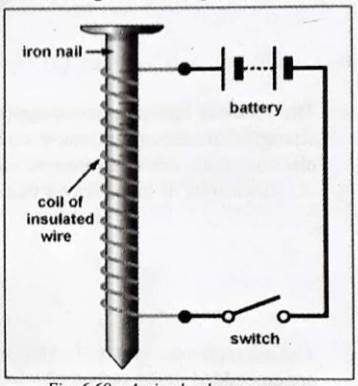


Fig. 6.69 : A simple electromagnet.

The magnetic field around an electromagnet is just the same as the one around a bar magnet. It can, however, be reversed by turning the battery around. Unlike bar magnets, which are permanent magnets, the magnetism of electromagnets can be turned on and off just by closing or opening the switch.

Uses of electromagnet

1. For lifting and transporting large masses of iron scrap, girders, plates etc., especially to places where it is not convenient to take the help of human labour. Electromagnets are used to lift as much as 20-22 tonnes of iron in a single lift. To unload the magnet at the desired place, the current in the electromagnet is switched off so that the load drops.
2. For loading furnaces with iron.
3. For separating magnetic substances such as iron from other debris (e.g. for separating iron from the crushed copper ore in copper mines).
4. For removing pieces of iron from wounds.
5. In several electrical devices such as electric-bell, telegraph, electric tram, electric motor, relay, microphone, loud speaker, etc.
6. In scientific research to study the magnetic properties of a substance in a magnetic field.

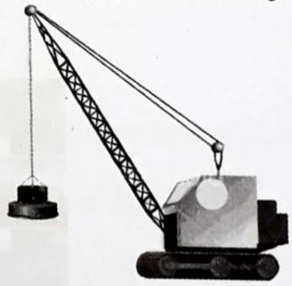


Fig. 6.70 : Electric Crane.

Some useful devices based on electromagnets produced by currents passing through solenoids:

Electric bell

Parts of an electric bell

P - Push button, E - Electromagnet, A - Soft iron armature, S - Flexible metal strip, C - Contact screw, H - Hammer, G - Gong

When the push button P is depressed, current will flow through the circuit, and this will energise the electromagnet, E. It will attract the soft iron armature, A, causing the hammer to strike the gong. Contact at the screw C, will be broken, de-energising the electromagnet. The flexible metal strip, S acts as a spring, pulling back the armature and the hammer, and restoring contact at the screw. This cycle is repeated as long as the push button is depressed.

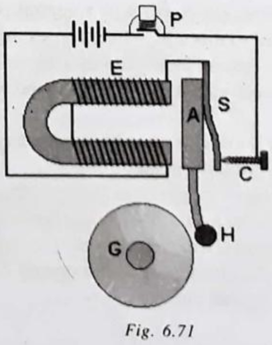


Fig. 6.71

Telephone

A typical telephone handset consists of two parts - the receiver (that you place next to your ear) utilises an electromagnet, and a microphone, into which you speak.

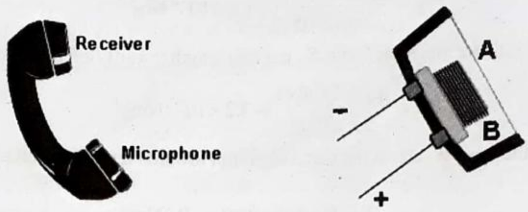


Fig. 6.72

The receiver has an electromagnet, B, connected to the circuit. Varying strengths of the current cause different amount of magnetisation of the electromagnet. The electromagnet causes deformation of the steel membrane, A. This results in sound waves that are picked up by the user's ear.

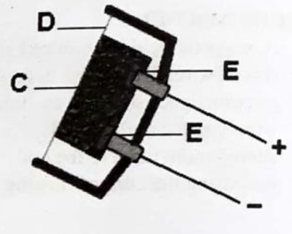


Fig. 6.73

The microphone consists of a steel membrane, D, lying across a small container of carbon powder, C. Two electrical contacts, E are embedded in the carbon powder, whose resistance depends on the density of the powder particles. Sound waves compress the powder to varying degrees, thus altering the resistance of the carbon powder. This in turn causes small changes in the current flowing through the circuit.

Loudspeaker

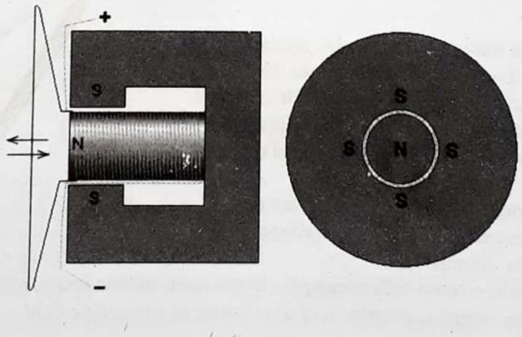


Fig. 6.74

A loudspeaker consists of a central pole, surrounded by a ring magnet, A movable coil, is wound around the central pole. Attached to this coil, which carries the current, is a cardboard cone.

When a current passes through the coil, a force acts on the coil forcing it to move in and out. The paper cone which is attached to it moves with it, and sets up sound waves, which reproduce the sounds which a microphone originally converted to a current.

Relays

A relay is a device whereby a secondary circuit can be switched on by a primary circuit.

Referring to the diagram above, when the switch S is closed, the iron core inside the solenoid becomes magnetised. It attracts the armature, which is pivoted. The upper limb of the armature causes the contacts in the secondary circuit XY to close, thus activating that circuit.

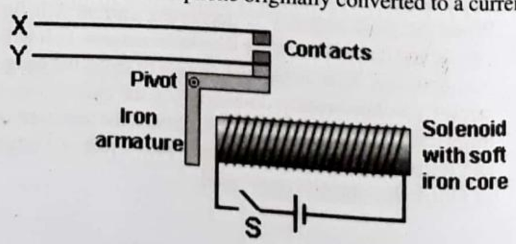


Fig. 6.75

DC MOTOR

A d.c. motor converts direct current energy from a battery into mechanical energy of rotation.

Principle : It is based on the fact that when a coil carrying current is held in a magnetic field, it experiences a torque, which rotates the coil.

Construction : It consists of the five parts.

Armature : The armature coil ABCD consists of a large number of turns of insulated copper wire wound over a soft iron core.

Field Magnet : The magnetic field is supplied by a permanent magnet NS.

Split-rings or Commutator : These are two halves of the same ring. The ends of the armature coil are connected to these halves which also rotate with the armature.

Brushes : These are two flexible metal plates or carbon rods B_1 and B_2, which are so fixed that they constantly touch the revolving rings.

Battery : The battery consists of a few cells of voltage V connected across the brushes. The brushes convey the current to the rings, from where it is carried to the armature.

Working : The battery sends current through the armature coil in the direction shown in figure. Applying Fleming's Left Hand Rule, CD experiences a force directed inwards and perpendicular to the plane of the coil. Similarly, AB experiences a force directed outwards and perpendicular to the plane of the coil. These two forces being equal, unlike and parallel form a couple. The couple rotates the armature coil in the anticlockwise direction. After the coil has rotated through 180°, the direction of the current in AB and CD is reversed, figure. Now CD experiences an outward force and AB experiences an inward force. The armature coil thus continues rotating in the same i.e., anticlockwise direction.

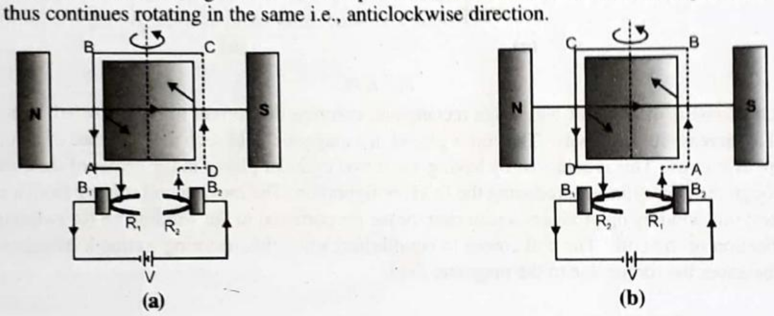


Fig. 6.76

Efficiency of the d.c. motor : Since the current I is being supplied to the armature coil by the external source of e.m.f. V, therefore,

Input electric power = VI

According to Joule's law of heating, Power lost in the form of heat in the coil = $I^2 R$

If we assume that there is no other loss of power, then Power converted into external work i.e.,

Output mechanical power = $VI - I^2 R = (V - IR) I = EI$

$\therefore$ Efficiency of the d.c. motor, $\eta = \dfrac{\text{Output mechanical power}}{\text{Input electric power}}$

A d.c. motor delivering maximum output has an efficiency of only 50%.

Uses : (1) The d.c. motors are used in d.c. fans (exhaust, ceiling or table) for cooling and ventilation.

(2) They are used for pumping water.

(3) Big d.c. motors are used for running tram-cars and even trains.

AC Motor

As in the DC motor case, a current is passed through the coil, generating a torque on the coil. Since the current is alternating, the motor will run smoothly only at the frequency of the sine wave. It is called a synchronous motor. More common is the induction motor, where electric current is induced in the rotating coils rather than supplied to them directly.

One of the drawbacks of this kind of AC motor is the high current which must flow through the rotating contacts. Sparking and heating at those contacts can waste energy and shorten the lifetime of the motor. In common AC motors the magnetic field is produced by an electromagnet powered by the same AC voltage as the motor coil. The coils which produce the magnetic field are sometimes referred to as the "stator", while the coils and the solid core which rotates is called the "armature". In an AC motor the magnetic field is sinusoidally varying, just as the current in the coil varies.

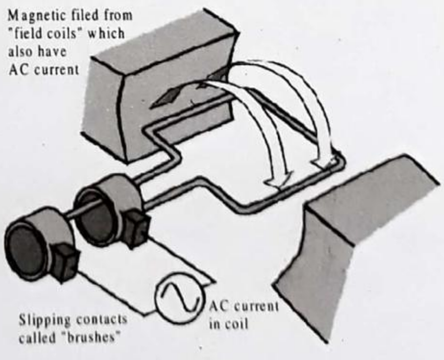


Fig. 6.77

Galvanometer

The torque on a current loop in a uniform magnetic field is used to measure electrical magnetic field is used to measure electrical currents. This current measuring device is called a moving coil galvanometer.

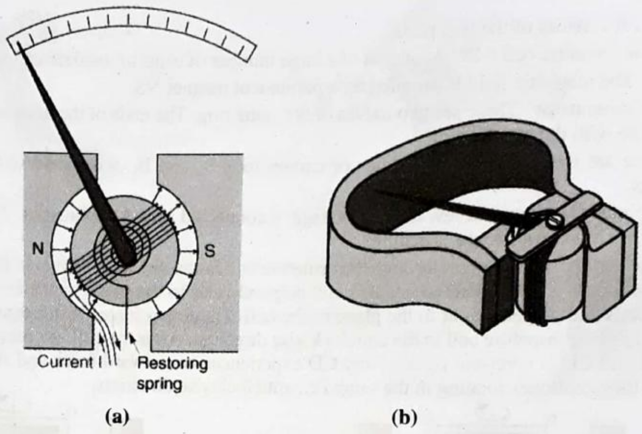


Fig. 6.78

The galvanometer consists of a coil of wire often rectangular, carrying the current to be measured. There are generally many turns in the coil to increase its sensitivity. The coil is placed in a magnetic field such that the lines of B remain nearly parallel to the plane of wire as it turns. This is achieved by having a soft iron cylinder placed at the center of the coil. Magnetic field lines tend to pass through the iron cylinder, producing the field configuration. The moving coil is hung from a spring which winds up as the coil rotates; this winding up produces a restoring torque proportional to the winding up (or twisting) of the spring, i.e. to the angular deflection of the coil. The coil comes to equilibrium when this restoring torque k balances the torque due to the magnetic field balances the torque due to the magnetic field.

CHECK Point

- **How could a light bulb near, yet not touching, an electromagnet be lit? Is AC or DC required? Defend your answer.**

SOLUTION

For the bulb to be lit, AC should be supplied in the coil of the electromagnet so that an alternating magnetic field will be established in the region around it. This changing magnetic field will induce a current in the circuit of the light bulb and the bulb will glow.

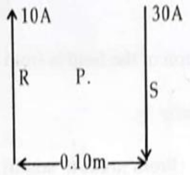
MISCELLANEOUS SOLVED EXAMPLES

1. Two identical wires R and S lie parallel in the horizontal plane, their axis being 0.10m apart. A current of 30A in S Neglecting the effect of the earth's magnetic flux density at a point P in the plane of the wires. If P is (i) mid way between R and S (ii) 0.05 m from R and 0.15m from S. [the permeability of free space $\mu_0 = 4\pi \times 10^{-7}\ \text{Hm}^{-1}$]

Sol. (i) Midway between R and S

Field due to R, $B_R = \dfrac{\mu_o I}{2\pi r}$

Field due to S, $B_s = \dfrac{\mu o I}{2\pi r}$



$$\frac{4\pi\times10^{-7}\times30}{2\pi\times0.05} = 12\times10^{-5}\text{T}$$

$\because$ Direction of B due to two wire is the same, total flux density,

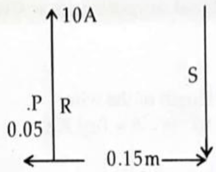
$B = B_R + B_S$

$= 4\times10^{-5} + 12\times10^{-5} = 16\times10^{-5} = 1.6\times10^{-4}\text{T}$

(ii) If P is 0.05 m from R and 0.15 m from S

$$B_R = \frac{\mu_0 I}{2\pi r} = \frac{4\pi\times10^{-7}}{2\pi\times0.05} = 4\times10^{-5}\text{T}$$

$$B_S = \frac{\mu_0 I}{2\pi r} = \frac{4\pi\times10^{-7}\times30}{2\pi\times0.15}$$



$\because$ B_R and B_S are in opposite direction

Resultant field $= B_S - B_R = 4\times10^{-5} - 4\times10^{-5} = 0$

2. In the figure X is a very long straight wire.Rectangle PQRS is suspended with PS 2 cm from x as shown the dimensions of PQRS are 10cm by 3cm, and current of 2A flows in the coil. Calculate the resultant force on PQRS in magnitude and direction.

Sol. The force on the side PS due to current X,

F=Bil

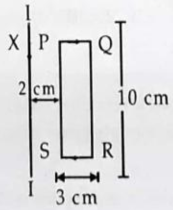
$$= \frac{\mu_o}{2\pi}\frac{i_x}{r}\times i\ell = \frac{4\pi\times10^{-7}}{2\pi}\times\frac{5}{2\times10^{-2}}\times0.10$$

$= 10\times10^{-6}$N along + ve x – axis

The force on the side QR due to current through X,

F=Bil

$$= \frac{\mu_o}{2\pi}\frac{i_x}{r}\times i\ell = \frac{4\pi\times10^{-7}}{2\pi}\times\frac{5}{5\times10^{-2}}\times2\times0.1$$



$= 4\times10^{-6}$ N along – ve x – axis

The force on PQ and SR due to the current carrying conductor are equal and opposite.

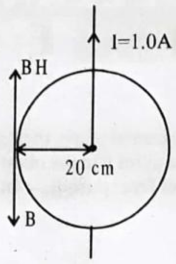
Hence the net force $= 10\times10^{-6} - 4\times10^{-6}$

$= 6\times10^{-6}$ N along +ve x–axis

3. Calculate the magnetic flux density at a point 20cm to the west of a long vertical wire carrying a current of 1.0A flowing up the wire. [the horizontal component of the earth's field at the point is 1.8×10^{-5}]

Sol. I = 1.0A, r = 20cm = 0.2m

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi\times10^{-7}\times1.0}{2\pi\times0.2} = 1.0\times10^{-6}\text{T} = 10\times10^{-5}\text{T}$$



From the right hand grip rule, the direction of the field is from north to south and the horizontal component of the earth's field is from south to north.
Hence the resulting magnectic flux density
$= 10 \times 10^{-5} T - 1.8 \times 10^{-5} T$
$= 8.2 \times 10^{-5} T$ (From north to south)

4. A horizontal straight wire 5 cm long weighing $1.2\ gm^{-1}$ is placed perpendicular to a uniform horizontal magnetic field of the flux density 0.6T. If the resistance of the wire is $3.8\ \Omega\ m^{-1}$ calculate the potential difference that has to be applied between the ends of the wire to make it just supporting ($g = 9.8\ ms^{-1}$)

Sol. $l = 5cm = 5 \times 10^{-2} m$
Mass of the wire,
m = mass per unit length × length of the wire.
$= 1.2 \times 10^{-3}\ kg\ m^{-1} \times 5 \times 10^{-2} m = 6 \times 10^{-5}\ Kg,$
$B = 0.6T$
Resistance of the wire
R = (Resistance per unit length x length of the wire)
$= 3.8 \times 5 \times 10^{-2} = 0\ 19\ \Omega$
Let V be the P.d. applied between the ends of the wire, for the wire to be self supporting:

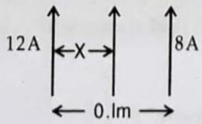
$$mg = BIl = B\frac{V}{R}l$$

$$\therefore\ V = \frac{mg \times R}{B\ell} = \frac{6\times10^{-5}\times9.8\times0.19}{0.6\times5\times10^{-2}} = 3.72\times10^{-3}\,V$$

5. Two long parallel conductors carry respectively currents of 12 and 8A respectively in the same direction. If the wires are 10 cm apart, find where the third parallel wire also carrying a current must be placed so that the force experienced by it shall be zero.

Sol. For the force on the third conductor to be zero, the direction of the flux density due to the current flowing in the two wires must be opposite in the position of the wire.
∴ The third wire must be placed between the wire. Let the third wire placed at a distance *x m* from the wire carrying 12A,
then, $B_1 = B_2$

$$\frac{\mu_0 I_1}{2\pi x} = \frac{\mu_0 I_2}{2\pi(0.1 - x)}$$



$$\text{or}\quad \frac{12}{x} = \frac{8}{0.1 - x}\ \text{or}\ \frac{3}{x} = \frac{2}{0.1 - x}$$

$$\text{or}\quad 0.3 = 5x = \frac{0.3}{5} = 0.06\,m$$

6. A rectangular loop of sides 25 cm and 10 cm carrying a current of 15 A is placed with its longer side parallel to a long straight conductor 2.0 cm apart carrying a current of 25 A. What is the net force on the loop?

Sol. Consider a rectangular loop PQRS placed near a long straight conductor AB as shown in figure. Due to the interaction of currents, the arm PQ of the loop will get attracted while arm RS will get repelled. Forces on the arms QR and SP will be equal and opposite and hence cancel out.

Here, $PQ = 25\text{ cm} = 25 \times 10^{-2}\text{ m}$,

$PS = 10\text{ cm} = 10 \times 10^{-2}\text{ m}$

Distance of PQ from AB,

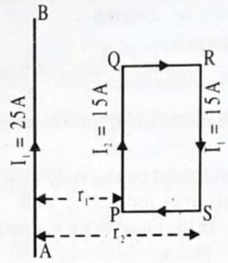
$r_1 = 2.0\text{ cm} = 2.0 \times 10^{-2}\text{ m}$

Distance of RS from AB,

$r_2 = 2.0 + 10 = 12.0\text{ cm} = 12.0 \times 10^{-2}\text{ m}$

Current through long wire AB, $I_1 = 25$ A

Current through rectangular loop, $I_2 = 15$ A



$\therefore$ Force on the arm PQ, $F_1 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_1} \times \text{length PQ}$

$$F_1 = \frac{10^{-1} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{2.0 \times 10^{-2}}$$

$= 9.375 \times 10^{-4}$ (towards AB)

Force on the arm RS,

$$F_2 = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r_2} \times \text{length RS} = \frac{10^{-7} \times 2 \times 25 \times 15 \times 25 \times 10^{-2}}{12 \times 10^{-2}}$$

$= 1.563 \times 10^{-4}$ (away from AB)

$\therefore$ Effective force on the loop,

$F = F_1 - F_2 = 9.375 \times 10^{-4} - 1.563 \times 10^{-4} = 7.812 \times 10^{4}$ N (towards AB)

7. A narrow vertical rectangular coil is suspended from the middle of its upper side with its plane parallel to a uniform horizontal magnetic field of 0.02 T. The coil has 10 turns and the lengths of its vertical and horizontal sides are 0.1 m and 0.05 m respectively. Calculate the torque on the coil when a current of 5A is passed into it. What would be the new value of the torque if the plane of the vertical coil was initially at 60° to the magnetic field and a current of 5A was passed into the coil.

Sol. $B = 0.02$ T, $N = 10$ Turns

$A = l \times b = 0.1 \times 0.05 = 0.005\text{ m}^2$

$I = 5$A

Torque $= BINA = 0.02 \times 5 \times 10 \times 0.005$

$= 0.005\text{ Nm} = 5 \times 10^{-3}\text{Nm}$

New value of the torque when the plane of the vertical coil was at 60° to the magnetic field.

$= BINA\cos\theta = 5 \times 10^{-3}\cos 60^\circ$

$= 5 \times 10^{-3} \times ½ = 2.5 \times 10^{-3}$ Nm.

1 EXERCISE

FIB Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. A compass needle is a .... magnet.
2. Field lines are used to represent a ....
3. Field lines are shown closer together where the magnetic field is ....
4. A metallic wire carrying an electric current has associated with it a .... field.
5. The field lines about the wire consist of a series of concentric circles whose direction is given by the .... rule.
6. The magnetic lines of force are the lines drawn in a magnetic field along which a .... pole would move.
7. An electric current can be used for making temporary magnets known as ....
8. The unit of magnetic field is ....
9. The S.I. unit of magnetic flux ....
10. The force between currents is called the .... force.
11. The N-pole of a compass points to the .... pole of a permanent magnet.
12. The force that a magnetic field exerts on a current is always perpendicular to the .... and to the ....
13. In a magnetic field pointing away from you, an electron traveling to the right will experience a force in the .... direction.
14. Magnetic fields are produced by ....
15. You are looking into a solenoid, at its S-pole, along its axis. From your view point, the direction of the current in the solenoid is ....
16. Crowding the wires of a solenoid more closely together will .... the strength of the field inside it.
17. A paramagnet magnet behaves like a solenoid because both contain currents in the form of ....
18. Magnetic field lines emerge from the .... pole of a solenoid or a permanent magnet.
19. You are looking down the axis of a solenoid, and the current from your position is clockwise. The end of the solenoid facing you is a .... pole.

T/F True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Energy associated with an electric field is analogous to potential energy whereas the energy associated with the magnetic field is analogous to kinetic energy.
2. No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field.
3. An electron and a proton move in a uniform magnetic field with same speed perpendicular to the magnetic field. They experience forces in opposite directions differing by a factor of 1840.
4. A positive charge projected along the axis of a current carrying solenoid moves undeviated from its original path.
5. There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.
6. An electron does not suffer any deflections while passing through a region. This makes sure that there is no magnetic field in that region.
7. The field at the centre of a long circular coil carrying current will be parallel straight lines.
8. A magnetic field exists in the region surrounding a magnet, in which the force of the magnet can be detected.
9. The pattern of the magnetic field around a conductor due to an electric current flowing through it depends on the shape of the conductor.
10. A current-carrying conductor when placed in a magnetic field always experiences a force.
11. 'Lodestone' is a naturally occurring magnet.
12. The direction of force on a current carrying conductor placed in a magnetic field can be reversed by reversing the direction of current flowing in the conductor.
13. The direction of force on a current carrying conductor placed in a magnetic field cannot be reversed by reversing the direction of magnetic field.
14. Two magnetic lines of force never intersect each other.
15. The field lines inside the infinite solenoid are in the form of parallel straight lines.

MTF Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

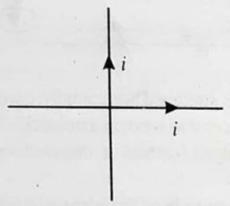
1.

Column I	Column II
(A) Work done by the magnetic force may be	(p) zero
(B) Work done by the pseudo force may be	(q) ±ve, zero
(C) Frictional work	(r) Conservative
(D) Change in kinetic energy of charge particle in magnetic field.	(s) Non conservative

2. Column II gives approximate values of magnetic fields due to source given in column I

Column I		Column II	
(A)	At surface of neutron star	(p)	10^{-10} T
(B)	Near big electromagnet	(q)	1.5 T
(C)	At earth surface	(r)	10^{8} T
(D)	In interstellar space	(s)	10^{-4} T

3. Equal currents i flow in two wires along x and y axis as shown. Match the following :



Column I		Column II	
(A)	Magnetic field in first quadrant	(p)	inwards
(B)	Magnetic field in second quadrant	(q)	outwards
(C)	Magnetic field in third quadrant	(r)	may be inwards or outwards
(D)	Magnetic field in fourth quadrant		

VSAQ *Very Short Answer Questions :*

DIRECTIONS : *Give answer in one word or one sentence.*

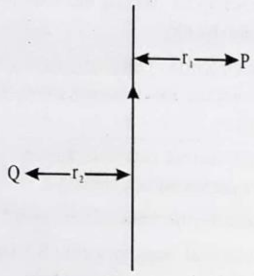
1. Why does a compass needle get deflected when brought near a bar magnet?
2. A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it ?
3. Why don't two magnetic lines of force intersect each other?
4. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
5. List three sources of magnetic fields.
6. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
7. What do you conclude from Oersted's experiment?
8. Name the types of electromagnets commonly used.
9. When can an electric charge give rise to a magnetic field?
10. Why is soft iron used as the core of the electromagnet used in electric bell ?
11. How will the direction of force be changed, if the current is reversed in the conductor placed in a magnetic field?
12. Describe a set up for plotting the magnetic lines of force in a straight conductor.
13. What is the direction of magnetic field at the centre of a coil carrying current in (i) clockwise (ii) anticlockwise direction?
14. Why does a current carrying, freely suspended solenoid rest along a particular direction ?
15. What constitutes the field of a magnet?
16. Name the physical quantity whose S.I. unit is Wb - m^2. Is it a scalar quantity or vector quantity?
17. Name the rule used to find the direction of force on a current carrying conductor.
18. What is the greatest disadvantage with a suspended-type moving coil galvanometer?
19. If the length of the suspension wire is increased does the sensitivity of a moving coil galvanometer increase or decrease?
20. If a mirror of greater radius of curvature replaces the mirror of a moving coil galvanometer, does the sensitivity of the galvanometer, does the sensitivity of the galvanometer increase or decrease?
21. Why are the pole pieces of a galvanometer made concave?

SQA *Short Answer Questions :*

DIRECTIONS : *Give answer in 2-3 sentences.*

1. State two ways through which the strength of an electromagnet can be increased.
2. State three factors on which, the magnitude of force on a current carrying conductor placed in a magnetic field, depends. Can this force be zero for some position of the conductor?
3. What do you mean by an electromagnet ? With the help of diagrams show the two types of electromagnets. Give two uses of electromagnets.
4. How will you experimentally show that a current-carrying conductor experiences a force when kept in a magnetic field?
5. Under what conditions permanent electromagnet is obtained if a current carrying solenoid is used? Support your answer with the help of a labelled circuit diagram.

6. AB is a current carrying conductor in the plane of the paper as shown in Figure. What are the directions of magnetic fields produced by it at points P and Q? Given $r_1 > r_2$, where will the strength of the magnetic field be larger?

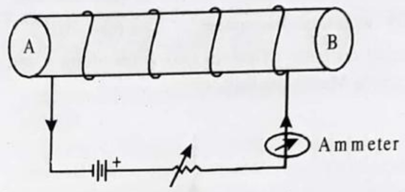


7. Meena draws magnetic field lines of field close to the axis of a current carrying circular loop. As she moves away from the centre of the circular loop she observes that the lines keep on diverging. How will you explain her observation.
8. What does the divergence of magnetic field lines near the ends of a current carrying straight solenoid indicate?
9. List the properties of magnetic lines of force.
10. What is the magnetic field that exerts a force of 2.4×10^{-4} newtons on a current of 12 amperes in a wire 30 cm long set perpendicular to the field ?
11. A wire carrying 1.5 amp has a length of 20 cm in a magnetic field of 40 milliteslas. If the wire is perpendicular to the field, how much force does the field exert on the wire ?
12. What is the direction of the force that a vertical magnetic field, directed upward, will exert on an electron traveling eastward in it.
13. What is the shape of magnetic field lines around a circular current carrying conductor?
14. What is Solenoid?
15. Why is soft iron generally used as the core of the electromagnet?
16. State four factors on which the strength of electromagnet depends.

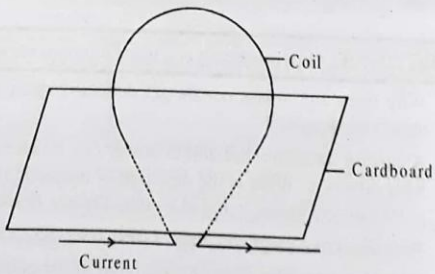
LAQ *Long Answer Questions :*

DIRECTIONS : *Give answer in four to five sentences.*

1. What is the nature of magnetic field produced by a straight current carrying conductor? Explain with the help of an experiment.
2. Diagram below shows a circuit containing a coil wound over a long and thin hollow carboard tube. Copy the diagram (i) Show the polarity acquired by each face of the solenoid. (ii) Draw the magnetic field lines of force inside the coil and also show their direction. (iii) Mention two methods to increase the strength of the magnetic field inside the coil.



3. A 0.4m wire, stretched horizontally, carries an electric current of 15A from east to west, in a magnetic field whose magnetic field intensity is 0.1 N/Am, directed vertically downwards. What is
   (a) the magnitude of the magnetic deflecting force on the wire, and
   (b) its direction?
4. A straight conductor passes vertically through a cardboard sprinkled with iron filings. Show the setting of the iron filings when a weak current is passed in the downward direction. What changes occur if,
   (i) the strength of the current is increased.
   (ii) the single conductor is replaced by several parallel conductors with current flowing in the same. direction.
5. The diagram shows a current carrying coil passing through a sheet of stiff cardboard. Draw three lines of magnetic field on the cardboard.



State two factors on which the magnitude of magnetic field at the centre of coil, depends.
6. Draw a labelled diagram to make an electromagnet from a soft iron bar. Mark the polarity at its ends. What precaution would you observe ?

2 EXERCISE

Multiple Choice Questions :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Choose the correct option(s).
The magnetic field inside a long straight solenoid-carrying current
(a) is zero.
(b) decreases as we move towards its end.
(c) increases as we move towards its end.
(d) is the same at all points.

2. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is
(a) towards south (b) towards east
(c) downward (d) upward

3. Which of the following correctly describes the magnetic field near a long straight wire?
(a) The field consists of straight lines perpendicular to the wire.
(b) The field consists of straight lines parallel to the wire.
(c) The field consists of radial lines originating from the wire.
(d) The field consists of concentric circles centred on the wire.

4. A magnet is placed vertically on a paper. Then the number of neutral points obtained on the paper is
(a) zero (b) one
(c) two (d) three

5. A small magnet is placed perpendicular to a uniform magnet field. The forces acting on the magnetic will result in
(a) Rotational motion
(b) Translatory motion
(c) No motion at all
(d) Translational and rotational motion both

6. A charge of 1.6×10^{-19} coulomb enters in the magnetic field of 2 weber/m² normally with a velocity of 10^5 m/sec. The force on the charge will be
(a) 3.2×10^{-14} N (b) 3.2×10^{-19} N
(c) 1.6×10^{-14} N (d) zero

7. The magnetic field at a point due to a current carrying conductor is directly proportional to the
(a) current flowing through the conductor
(b) Distance from the conductor
(c) Voltage across the conductor
(d) Resistance of the conductor

8. Which one of the following substances is the magnetic substances?
(a) Mercury (b) Iron
(c) Gold (d) Silver

9. Magnetic lines do not intersect one-another because
(a) they are at a distance
(b) they are in the same direction
(c) they are parallel to another
(d) at the point intersection there will be two direction of the magnetic force which is impossible

10. Instrument can be shielded from outside magnetic effects by surrounding them with
(a) Rubber shield (b) Glass shield
(c) Iron shield (d) Brass shield

11. The vertical plane which passes through the magnetic axis of a freely suspended magnetic at rest is called
(a) Magnetic meridian (b) Geographical meridian
(c) North meridian (d) South meridian

12. By removing the inducing magnet, the induced magnetism is
(a) Finished after some time
(b) Finished just after
(c) Not finished for a long time
(d) Not charged

13. The similar magnets of steel are .... than the magnets of soft iron
(a) stronger (b) of equal strength
(c) weaker (d) none of the above

14. A bar of soft iron is placed flat on the table. A bar magnet is taken and its south pole is placed on one end of the bar of soft iron. The magnet is held almost vertically. The bar is stroked from one end to the other with magnet. On the other end of the bar, magnet is lifted and again placed on the first end and the bar is again stroked. The end of the bar where the magnet is lifted will be
(a) south pole
(b) no pole
(c) south and north both type
(d) north pole

15. The angle of decilination at a place is the angle
(a) between the vertical plane and the geographical meridian
(b) between the vertical plane and the magnetic meridian
(c) between the geographical meridian and the magnetic meridian
(d) between the geographical meridian and horizontal plane

16. The magnetism in a magnet is mainly due to
(a) The orbital motion of the electrons
(b) The spin motion of the electrons
(c) The nuclear charge
(d) None of the above

17. When the north pole of a strong magnet is brought near to the north pole of a weak magnet then they will
(a) Attract each other
(b) repel each other
(c) first attract and then repel
(d) first repel and then attract

18. A magnet can be demagnetised by
(a) Hammering the magnet
(b) Putting it in the water
(c) Cooling it
(d) Putting in contact with iron

19. The effective length of the magnet is
(a) the complete length of the magnet
(b) the distance between the two poles of the magnet
(c) the half of the length of the magnet
(d) the square of the length of the magnet

20. When the bars of bismuth are placed between the magnetic poles they set their length
(a) perpendicular to the lines of force
(b) along the lines of force
(c) neither perpendicular nor along the lines of force
(d) In any direction

21. Two bars of soft iron exactly same are given. One of them is a magnet. Without using any thing more, how would you find which is a magnet
(a) By bringing two bars near and noting which one is attracting. The attracting one is a magnet
(b) By bringing two bars near and noting which one is repelling. One which repells is an ordinary iron.
(c) By rubbing one bar with the other and noting which becomes magnet. The bar which is magnetised is an ordinary iron
(d) One bar is placed flat horizontal on the table and the other bar is held vertical with its one end on the middle of first bar. If there is attraction between the two, the vertical bar is magnet otherwise ordinary iron.

22. Magnetic storms are due to
(a) the rotation of the earth
(b) the revolution of the earth
(c) the rainy season
(d) the appearance off sun spots

23. Which of the following processes will not produce new magnetic poles?
(a) cutting a bar magnet in half
(b) turning on a current in a solenoid
(c) running a current through a straight wire
(d) placing an iron rod in contact with a magnet

24. Magnetic field lines start
(a) on N-poles
(b) on S-poles
(c) on current-carrying wires
(d) Nowhere

25. The conductivity of a magnetic substance for the lines of force with respect to air is called the
(a) Magnetic induction
(b) magnetic permeability
(c) magnetic flux density
(d) intensity of magnetisation

26. Magnetic field lines form circles in the space
(a) near a permanent magnet
(b) around a current-carrying wire
(c) inside a solenoid
(d) inside a current-carrying loop

27. The angle of inclination of the axis of the magnetic needle to the horizontal plane when suspended freely and is at rest is known as
(a) angle of inclination (b) angle of variation
(c) angle of declination (d) none of the above

28. A tesla is equivalent to a
(a) newton per coulomb
(b) newton per ampere-meter
(c) ampere per newton
(d) newton per ampere-second

29. A vertical wire carries a current upward. The magnetic field north of the wire will be directed
(a) upward (b) eastward
(c) westward (d) northward

30. The magnetic flux is expressed in
(a) dynes (b) Oerested
(c) Gauss (d) Weber

31. The magnetic lines of force, inside a current carrying solenoid, are
(a) along the axis and are parallel to each other
(b) perpendicular to the axis and equidistance from each other
(c) circular and they do not intersect each other
(d) circular at the ends but they are parallel to the axis inside the solenoid.

32. In a moving coil galvanometer, the magnetic pole pieces are made cylindrical and a soft iron core is placed at the centre of the coil to make the magnetic field
(a) strong (b) strong and radial
(c) uniform (d) strong and uniform

33. Which of the following is not true
(a) Induction precedes attraction
(b) We cannot isolate a single pole
(c) We can magnetise an iron ring
(d) A permanent magnet retains its magnetism even when heated on a flame.

34. Wrist watches are made antimagnetic by shielding their machinery with
(a) plastic sheets
(b) a metal of high conductivity
(c) a magnetic substance of low permeability
(d) a magnetic substance of high permeability

35. Which of the following statement is not correct?
(a) The dip angle is the angle between the horizontal and earth's total magnetic field.
(b) Neutral points are obtained where the earth's magnetic field is perpendicular to that due to a magnet
(c) A magnetic field is a region in which a magnetic force can be detected.
(d) Magnetic fields are vector quantities

36. When a bar magnet is broken into two pieces?
(a) we will have a single pole on each piece
(b) each piece will have two like poles
(c) each piece will have two unlike poles
(d) each piece will be lose magnetism

37. The permanent magnets are kept with soft iron pieces at ends as keepers
(a) to magnetise the soft iron pieces
(b) to increase the strength of the magnets
(c) to avoid self demagnetisation
(d) for physical safety of the magnets

38. A small magnet is placed perpendicular to a constant magnetic field. The forces acting on the magnet will result in
(a) rotation
(b) translation
(c) no motion at all
(d) rotation as well as translation

39. The vertical component of the earth's magnetic field is
(a) zero at the magnetic pole
(b) zero at the geographic pole
(c) same everywhere
(d) zero at the magnetic equator

40. A small piece of a substance gas repelled when it is brought near a powerful magnet. The substance can be
(a) dimagnetic (b) paramagnetic
(c) ferromagnetic (d) non-magnetic

41. Which of the following statement is not correct about two parallel conductors carrying equal currents in the same direction?
(a) Each of the conductors will experience a force
(b) The two conductors will repel each other.
(c) There are concentric lines of force around each conductor
(d) Each of the conductors will move if not prevented from doing so

42. Which of the following determines the direction of magnetic field due to a current carrying conductor?
(a) Faraday's laws of electromagnetic induction
(b) Fleming's left-hand rule
(c) Lenz's rule
(d) Maxwell's cork screw rule

43. Along the direction of current carrying wire, the value of magnetic field is ?
(a) Zero
(b) Infinity
(c) Depends on the length of the wire
(d) Uncertain

44. To obtain maximum intensity of magnetic field at a point the angle between position vector of point and small elements of length of the conductor is
(a) 0 (b) $\pi/4$
(c) $\pi/2$ (d) π

45. The value of magnetic field due to a small element of current carrying conductor at a distance r and lying on the plane perpendicular to the element of conductor is
(a) zero
(b) maximum
(c) inversely proportional to the current
(d) none of the above

46. The value of intensity of magnetic field at a point due to a current carrying conductor depends
(a) Only on the value of current
(b) Only on a small part of length of conductor
(c) On angle between the line joining the given point to the mid point of small length and the distance between the small length of the point
(d) On all and the above

47. An electric current i is flowing in a circular coil of radius a. At what distance from the center of the axis of the coil will the magnetic field be $1/8^{th}$ of its value at the centre ?
(a) 3a (b) $\sqrt{3}$ a
(c) a/3 (d) $a/\sqrt{3}$

48. In a coaxial, straight cable, the central conductor and the outer conductor carry equal currents in opposite direction. The magnetic field is zero-
(a) outside the cable
(b) inside the inner conductor
(c) inside the outer conductor
(d) in between the two conductors

49. When the number of turns in a toroidal coil is doubled, the value of magnetic flux density will become
(a) four times (b) eight times
(c) half (d) double

50. By a current carrying toroid, whose area of cross-section is fixed, the magnetic induction produced will be -
(a) maximum at inner end
(b) maximum at outer end
(c) maximum at center of area of cross-section
(d) equal at whole area of cross-section

51. When an electron beam is moving in a magnetic field, then the work done is equal to the
(a) charge of electron
(b) magnetic field
(c) product of electronic charge and the magnetic field
(d) zero

52. Which of the following rays are not deflected by a magnetic field -
(a) α-rays (b) β-rays
(c) γ-rays (d) positive rays

53. Two parallel beams of electron moving in the same direction will
(a) repel each other
(b) attract each other
(c) not interact with each other
(d) annihilate each other

54. An inverse square law of distance is obeyed by-
(a) the force per unit length between two long straight parallel current-carrying conductors in vacuum.
(b) the electric field intensity outside an isolated charged sphere
(c) the magnetic flux density outside a long straight current-carrying wire
(d) the electrostatic potential

55. A current carrying loop lying in a magnetic field behaves like a.
(a) A magnetic dipole (b) magnetic pole
(c) magnetic material (d) non-magnetic material

MTOC More than One Correct :

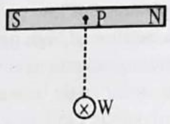
DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. Which of the following is/are valid for a current carrying circular coil?
(a) To induce magnetic induction of constant magnitude (at the centre of the coil), current required in it is directly proportional to its radius
(b) Induction of inducted magnetic field at the centre is inversely proportional to the radius of the coil
(c) Induction of the inducted magnetic field at the centre is directly proportional to the current flowing through the directly proportional to the current flowing through the coil
(d) None of the above

2. A current flows along the length of a long thin cylindrical shell:
(a) magnetic field at all the points lying inside the shell is zero
(b) magnetic field at any point outside the shell varies inversely with distance from the surface of the shell
(c) magnetic field strength is maximum just outside the shell
(d) none of the above

3. A proton moving with a constant velocity passes through a region of space without any change in its velocity. If E and B represent the electric and magnetic fields repectively, this region of space may have:
(a) $E=0, B=0$ (b) $E=0, B\neq 0$
(c) $E\neq 0, B=0$ (d) $E\neq 0, B\neq 0$

4. Figure shows a bar magnet and a long straight wire W carrying current into the plane of the paper. Point P is the point of inersection of axis of the magnet and the line of the shortest distance between the magnet and the wire.

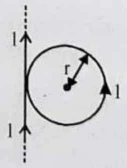


Which of the following statements is/are correct?
(a) If P is the midpoint of the magnet, the magnet experiences no torque
(b) If P is on the left of the midpoint of the magnet, the magnet experiences a leftward force as well as a torque
(c) If P is the midpoint of the megnet, the magnet experience a force along the line of the shortest distance
(d) None of the above

5. A straight conductor carries a current. Assume that all free electrons in the conductor move with the same drift velocity v. A and B are two observers on a straight line XY parallel to the conductor. A is stationary. B moves along XY with a velocity v in the direction of the free electrons.
(a) A and B observe the same magnetic field
(b) A observes a magnetic field, B does not
(c) A and B observe magnetic fields of the same magnitude but opposite directions
(d) A and B do not observe any electric field

6. A charged particle enters into a space and continues to move undeflected. Then in that space:
(a) a uniform horizontal electric field and a vertical magnetic field may be present
(b) a vertical electric field alone may be present
(c) uniform electric and magnetic fields, both directed vertically downwards, may be present
(d) a uniform horizontal magnetic field alone may be present

7. A long straight conductor, carrying a current I, is bent to form an almost complete circular loop of radius r on it. The magnetic field at the centre of the loop:



(a) is directed into the paper
(b) is directed out of the paper
(c) has magnitude $\frac{\mu_0 I}{2r}\left(1-\frac{1}{\pi}\right)$
(d) has magnitude $\frac{\mu_0 I}{2r}\left(1+\frac{1}{\pi}\right)$

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8. L is a circular ring made of a uniform wire. Current enters and leaves the ring through straight conductors which, if produced, would have passed through the centre C of the ring. The magnetic field at C:

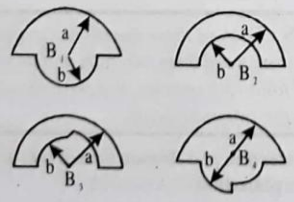
(a) due to the straight conductors is zero
(b) due to the loop is zero
(c) due to the loop is proportional to θ
(d) due to the loop is proportional to $(\pi - \theta)$

9. A flat circular coil carrying a current has a magnetic moment μ:
(a) μ has only magnitude; it does not have direction
(b) the direction of μ is along the normal to the plane of the coil
(c) the direction of μ depends on the direction of current flow
(d) the direction of μ does not change if the current in the coil is reversed

10. A current carrying ring is placed in a magnetic field. The direction of the field is perpendicular to the plane of the ring:
(a) there is no net force on the ring
(b) the ring will tend to expand
(c) the ring will tend to contract
(d) either (b) or (c) depending on the directions of the current in the ring and the magnetic field

11. A solenoid is connected to a source of constant e.m.f. for a long time. A soft iron piece is inserted into it. Then:
(a) self-inductance of the solenoid gets increased
(b) flux linked with the solenoid increases; hence, steady state current gets decreased
(c) energy stored in the solenoid gets increased
(d) magnetic moment of the solenoid gets increased

12. In the loops shown in figure all curved sections are either semicircles or quarter circles. All the loops carry the same current. The magnetic fields at the centres have magnitudes B_1, B_2, B_3 and B_4:



(a) B_4 is maximum (b) B_3 is minimum
(c) $B_4 > B_1 > B_2 > B_3$ (d) $B_1 > B_4 > B_3 > B_2$

FIP Fill in the Passage :

DIRECTIONS : *Fill in the blanks in the following passage(s) from the words given inside the box.*

I.

magnet, carrying, magnetic effect, electricity, magnitude of current, deflection increases, eastwards, southwards.

Oersted was the first to put forth the direct relation between ....1........ and magnetism. He conducted several experiments to determine the ....2.......... of a current ....3.......... wire. The following describes the Oersted experiment conducted to establish that a current carrying wire acts as a ....4.............

A long straight wire is connected to an external battery and an electric current is passed through it. When a magnetic needle is placed below the wire such that the wire is parallel to the axis of the magnetic needle and the current flows in the south to north direction, a deflection in the needle is observed. It is observed that the north pole of the needle is deflected westwards and as the ....5.......... is increased, the deflection, ...6........... till the north pole of the needle turns towards exact west. It is also observed that if instead of placing the magnetic needle below the wire, if it was placed above the wire, the north pole of the magnetic needle is deflected ....7................ .

II.

poles, attracts, east-west, north-south like, opposite, repel, magnetic

A magnet ....1......... small pieces of iron, nickel, cobalt, etc. The magnetic force of attraction is maximum is small regions near the ends of the magnet. These are called the ....2........ of the magnet.

A freely suspended magnet always points in ......3...... direction. The end pointing towards north is called north seeking pole or north pole. The other end which points towards south is called south seeking pole or south pole.

All magnets attract ....4.......... poles of other magnets and also a few substances like iron, nickel and cobalt. Thus if an unknown substance is attracted by a magnet, we cannot be sure whether it is a magnet. But like poles of magnet ....5............ each other. Hence if there is repulsion between an unknown substance and a magnet, we can be sure that the unknown substance is a magnet. The substances and a magnet, we can be sure that the unknown substance is a magnet. The substances which are attracted by magnets are called ......6...... substances.

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III. concentric circles, centre, opposite, polarity, straight conductor, reversed, same, circluar conductor.

The magnetic field produced around a straight current carrying conductor is in the form of ....1............ with the ....2............ lying on the straight conductor.

Take a copper wire AB. Pass it through a cardboard. Connect the wire to a battery through a key. Sprinkle some iron filings on the cardboard. Switch on the key and tap the cardboard gently. You will find that the iron filings arrange themselves in the form of concentric circles. Reverse the direction of current by changing the ....3........... of the battery. You will find that this time too, the iron filings arrange themselves in concentric circle but in ....4............ direction.

Hence, the magnetic field lines of force around a ....5........... carrying electric current are concentric circles with the conductor at the centre. The direction of magnetic field changes if the direction of current is ....6..............

PBQ Passage Based Questions :

Passage - I

An electron with kinetic energy K_e travels in a circular path that is perpendicular to a uniform magnetic field, the electron's motion subject only to the force due to the field.

1. The magnetic dipole moment of the electron due to its orbital motion has magnitude :

(a) K_eB (b) $\frac{K_eB}{2}$

(c) K_e/B (d) $K_e/2B$

2. The magnetic dipole moment of a positive ion with kinetic energy K under the same circumstances :

(a) K_iB (b) K_i/B

(c) $K_i/2B$ (d) Zero

3. An ionized gas consists of 5.3×10^{21} electrons/m^3 and the same number density of ions. Take the average electron kinetic energy to be 6.2×10^{-20} J and average ion kinetic energy to be 7.6×10^{-21} J. The magnetisation of the gas when it is in a magnetic field of 1.2 T is

(a) 150 A/m (b) 215 A/m

(c) 295 A/m (d) 310 A/m

Passage - II

Take a tightly-wound solenoid of radius a and length ℓ. the number of turns per unit length in it is n. It carries current i. Consider a small element of length dx of the solenoid at a distance x from one end. This contains ndx turns and can be assumed as a current carrying loop. The magnetic field due to whole solenoid will be the sum of magnetic field due to such elements.

1. The magnetic field due to this solenoid at the centre of its axis is :

(a) $\frac{\mu_0 i}{2a}$ (b) $\frac{\mu_0 n i}{2a}$

(c) $\frac{\mu_0 ni}{\sqrt{1+\frac{a^2}{\ell^2}}}$ (d) $\frac{\mu_0 n i}{\sqrt{1+\frac{4a^2}{\ell^2}}}$

2. The magnetic field due to the solenoid at the centre of its axis in the situation $a >> \ell$ is :

(a) $\frac{\mu_0 n i}{2}$ (b) $\mu_0 ni$

(c) $\frac{\mu_0 ni\ell}{2a}$ (d) $\frac{\mu_0 ni\ell}{a}$

3. The magnetic field due to the solenoid at the centre of its axis in the situation a << ℓ is :

(a) zero (b) $\frac{\mu_0 n i}{2}$

(c) $\mu_0 ni$ (d) infinite

Passage - III

In a television tube, each of the electrons in the beam has a kinetic energy of 12.0 keV. The tube is oriented so that the electrons move horizontally from geomagnetic south to geomagnetic north. The vertical component of earth's magnetic field points down and has a magnitude of 55.0 μT.

1. The direction in which beam deflects :

(a) east (b) west

(c) north-east (d) south-west

2. The acceleration of any electron due to the magnetic field is :

(a) $3.14\times10^{14}\,m/s^2$ (b) $4.28\times10^{14}\,m/s^2$

(c) $5.56\times10^{12}\,m/s^2$ (d) $6.28\times10^{14}\,m/s^2$

3. The transverse deflection of the beam after travelling 20.0 cm through the television tube :

(a) 1.96 mm (b) 2.98 mm

(c) 4.24 mm (d) none of these

A&R Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.

(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.

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(c) If **Assertion** is **correct** but **Reason** is **incorrect**.

(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** A direction current flows through a metallic rod, produced magnetic field only outside the rod.
Reason : There is no flow of charge carriers inside the rod.

2. **Assertion :** A proton moves horizontally towards a vertical long conductor having an upward electric current. It will deflect vertically downward.
Reason : Seeing the proton and the conductor from the side of the proton, the magnetic field at the site of the proton will be towards right. Hence the force $\vec{F} = q\vec{v} \times \vec{B}$ will deflect the proton vertically downward.

3. **Assertion :** Force experienced by moving charge will be maximum if direction of velocity of charge is perpendicular to applied magnetic field.
Reason : Force on moving charge is independent of direction of applied magnetic field.

4. **Assertion :** A neutral body may experience a net nonzero magnetic force.
Reason : The net charge on a current carrying wire is zero, but it can experience a force in a magnetic field.

5. **Assertion :** There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.
Reason : Work done by centripetal force is always zero.

6. **Assertion:** When two long parallel wires, hanging freely are connected in series to a battery, they come closer to each other.
Reason : Wires carrying current in opposite direction repel each other.

7. **Assertion :** A solenoid tends to expand, when a current passes through it.
Reason : Two straight parallel metallic wires carrying current in same direction attract each other.

8. **Assertion :** In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field.
Reason: Force on free electrons due to magnetic field always acts perpendicular to its direction of motion.

9. **Assertion :** A small coil carrying current, in equilibrium, is perpendicular to the direction of the uniform magnetic field.
Reason : Torque is maximum when plane of coil and direction of the magnetic field are parallel to each other.

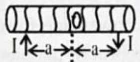
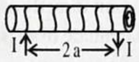
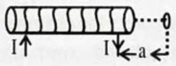
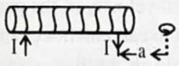
10. **Assertion :** Basic difference between an electric line and magnetic line of force is that former is discontinuous and the later is continuous or endless.
Reason : No electric lines of force exist inside a charged body but magnetic lines do exist inside a magnet.

11. **Assertion :** No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field.
Reason : Force on coil in magnetic field is always non-zero.

MMQ *Multiple Matching Questions :*

DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

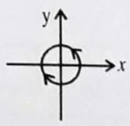
1. In column I, the positions of small current carrying loops have been shown and in column II information related to force experienced by coil is given. Match the entries of column I with the entries of column II. (Assume solenoid radius to be small as compared to its length)

Column-I	Column-II
A. 	p. Attractive
B. 	q. Repulsive
C. 	r. Zero
D. 	s. Initially zero, then starts Increasing

2. In magnetic field, for a charged particle, match the entries of column I with the entries of column II.

Column I	Column II
A. Acceleration	p. may be zero
B. Velocity	q. is zero
C. Speed	r. may be constant
D. Kinetic energy	s. is constant

3. A circular current carrying loop is placed in x-y plane as shown in figure. A uniform magnetic field $\vec{B} = B_0\hat{k}$ is present in the region. Match the entries of column I with the entries of column II.



Column I	Column II
A. Magnetic moment of the loop is	p. Zero
B. Torque on the loop is	q. maximum
C. Potential energy of the loop is	r. along + ve z- axis
D. Equilibrium of the loop is	s. stable
	t. None

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HOTS Subjective Questions :

DIRECTIONS : *Answer the following questions.*

1. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
2. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
3. Two charged particles are projected into a magnetic field that is perpendicular to their velocities. If the charges are deflected in opposite directions, what does this tell you about the particles?
4. A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it ?
5. A magnetic field that varies in magnitude from point to point but has a constant direction (east to west) is set up in a chamber. A charged particle enters the chamber and travels undeflected along a straight path with constant speed. What can you say about the initial velocity of the particle?
6. An electron travelling west to east enters a chamber having a uniform electrostatic field in north to south direction. Specify the direction in which a uniform magnetic field shoulu be set up to prevent the electron from deflecting from its straight line path.
7. An electron in passing through a field but no forces acting on it. Under what condition it is possible, that the motion of the electron will be in the (i) electric field (ii) magnetic field?
8. The energy of a charged particle moving in a uniform magnetic field does not change. Explain
9. A loop of irregular shape carrying current is located in an external magnetic field. If the wire is flexible, why does it change to a circular shape?
10. An electron does not suffer any deflection while passing through a region. Are you sure that there is no magnetic field? Is the reverse definite ?
11. Why is pure iron not used for making permanent magnets? Name one materials used for making permanent magnets. Describe how permanent magnets are made electrically. State two examples of electrical instruments made by using permanent magnets.
12. The flow of a current in a circular loop of wire creates a magnetic field at its centre. How may existence of this field be detected? State the rule which helps to predict the direction of this magnetic field.
13. How does the strength of the magnetic field at the centre of a circular coil of wire depend on :
    (i) the radius of the coil
    (ii) the number of turns of wire in the coil
    (iii) the strength of current flowing in the coil ?
14. How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is doubled and the radius is halved?

SOLUTIONS

Brief Explanations of Selected Questions

Exercise 1

FILL IN THE BLANKS :

1.	small	**2.**	magnetic field
3.	greater.	**4.**	magnetic
5.	right-hand	**6.**	north magnetic
7.	electromagnets	**8.**	tesla
9.	Weber	**10.**	magnetic
11.	S	**12.**	field, current
13.	downward	**14.**	currents
15.	clockwise	**16.**	increase
17.	circles	**18.**	None
19.	south		

TRUE / FALSE

1.	True	**2.**	True	**3.**	False	**4.**	True
5.	False	**6.**	True	**7.**	True	**8.**	True
9.	True	**10.**	False	**11.**	True	**12.**	True
13.	False	**14.**	True	**15.**	True		

MATCH THE FOLLOWING :

1. (A) → p, (B) → q, (C) → s, (D) → p

2. (A) → r, (B) → q, (C) → s, (D) → p

3. (A) → r, (B) → q, (C) → r, (D) → p

VERY SHORT ANSWER QUESTIONS :

1. A compass needle gets deflected when brought near a bar magnet because magnetic force is exerted by the bar magnet on the compass needle, which is itself a tiny pivoted magnet.

2. The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south. The direction of magnetic field at a point directly above the wire is from south to north.

3. Two magnetic lines of force never intersect each other. If the lines intersect, then at the point of intersection there would be two directions (the needle would point towards two directions) for the same magnetic field, which is not possible.

4. Direction of magnetic field inside the loop – Perpendicular to the plane of paper inward and
Direction of magnetic field outside the loop – Perpendicular to the plane of paper outward.

5. (a) Natural and artificial magnets. (b) Electromagnets (c) A current carrying conductor produces magnetic field.

6. The force experienced by a current-carrying conductor placed in a magnetic field is largest when the direction of current is at right-angles to the direction of the magnetic field.

7. Oersted's experiment demonstrates the magnetic effect of current. It showed experimentally that the current flowing through a conductor produces a magnetic field.

8. (i) Bar type (ii) Horse shoe type

13. (i) Along the axis of the coil inwards
(ii) Along the axis of the coil outwards.

15. Magnetic field lines at any point constitute the field of a magnet indicating that a north pole experiences a force at that point.

16. Magnetic field. It is a vector quantity.

17. Fleming's left hand rule.

18. It is not portable.

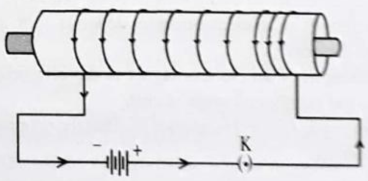
19. Sensitivity increases.

20. It remains unchanged.

21. The concave pole pieces provide a radial magnetic field, which is strong.

SHORT ANSWER QUESTIONS :

5. (i) The current through the solenoid should be direct current.
(ii) The rod inside is made of a magnetic material such as steel.



6. Into the plane of paper at P and out of it at Q. The strength of the magnetic field is larger at the point located closer i.e. at Q.

7. Strength of the magnetic field falls as distance increases. This is indicated by the decrease in degree of closeness of the lines of field.

8. The divergence, that is, the falling degree of closeness of magnetic field lines indicates the fall in strength of magnetic field near and beyond the ends of the solenoid.

9. (i) The direction of the magnetic field is indicated by the arrow in the line at any point (Tangent).
(ii) The field lines come out of the north pole and get into the south pole (closed loops are formed).

(iii) The strength of magnetic field is indicated by the closeness of the field lines. Closer the lines, more will be the strength and farther the lines, lesser will be the field strength.

(iv) No two field lines will intersect each other if they intersect there will be two different directions for field at the same point which is not impossible.

10. The current is perpendicular to the field, $B = \frac{F}{I\ell}$

Therefore, $B = \frac{2.4\times10^{-4}\,N}{(12A)\,(0.30m)} = 6.7\times10^{-5}\,N/A.m$

Since 1mT is 10^{-3} N/A.m, the answer can be written as 0.067 mT

11. With the wire perpendicular to the field,

$F = I\ell B = (1.5A)\,(0.20m)\,(0.040T) = 0.012\,N$

12. Point you left fingers upward, since your are dealing with a negative charge. Rotate your hand until the thumb points east. Your palm will point northward, and that is the direction of the force.

13. Concentric lines around the two ends of the conductor and straight lines at the centre of the conductor.

14. A cylindrical coil of many tightly wound turns of insulated wires with generally diameter of the coil smaller than its length is called a solenoid.

15. (i) Soft iron has less retentivity so it acquires the magnetic properties only when the current flows through the coil wound on it and loses the magnetic properties as the current is switched off.

(ii) The soft iron intensifies the magnetic field of the electromagnet because of its high permeability.

16. Factors on which the strength of an electromagnet depends are:

(1) Strength of electromagnet is directly proportional to the diameter of coil (Area of cross-section).

(2) Strength of an electromagnet depends upon the nature of the core.

(3) Strength of an electromagnet is directly proportional to the number of turns in coil.

(4) Strength of electromagnet is directly proportional to current.

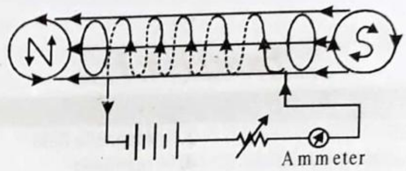
LONG ANSWER QUESTIONS :

1. The magnetic field produced around a straight current carrying conductor is in the form of concentric circles with the centre lying on the straight conductor.

Take a copper wire AB. Pass it through a cardboard. Connect the wire to a battery through a key. Sprinkle some iron filings on the cardboard. Switch on the key and tap the cardboard gently. You will find that the iron filings arrange themselves in the form of concentric circles. Reverse the direction of current by changing the polarity of the battery. You will find that this time too, the iron filings arrange themselves in concentric circle but in opposite direction.

Hence, the magnetic field lines of force around a straight conductor carrying electric current are concentric circles with the conductor at the centre. The direction of magnetic field changes if the direction of current is reversed.

2. (i) The polarity acquired by the two ends is as shown below. (A shows North and B shows South polarity

(ii) 

(iii) Increase the strength of current, increase the number of turns in the coil, insert soft iron rod in the coil.

3. (a) Given : Length of the wire $(\ell) = 0.4\,m$

Current (I) = 15A

Magnetic induction (B) = 0.1 N/Am

To calculate : (i) Force (F) = ? (ii) Direction = ?

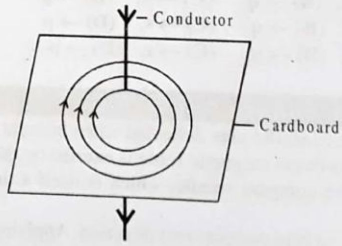
Formula to be used : $F = BI\ell$

Substituting the given values,

$F = 0.1\times15\times0.4 = 0.6\,N$

(b) By Fleming's left hand rule, forefinger (magnetic field) points vertically downwards, the middle finger (current) points west and the thumb (force) points towards the south.

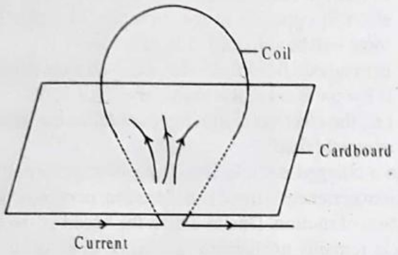
4. Figure shows the setting of the iron filings.



(i) The shape of distribution of iron filings remains unchanged but they get arranged upto a larger distance from the conductor when the strength of current is increased. This is because on increasing the strength of current, the strength of the magnetic field is increased and it is effective upto a larger distance from the conductor.

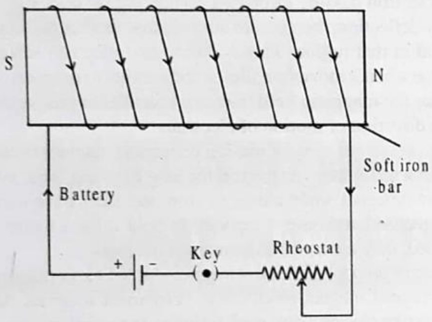
(ii) Magnetic field strength is increased so the iron filings get arranged upto a larger distance.

5. Figure represents the magnetic lines of force due to current carrying coil.



The magnitude of magnetic field at the centre depends on (i) the strength of current in the coil and (ii) the radius of coil.

6. The labelled diagram is shown in figure.



Precaution : The source of current must be the d.c. source.

Exercise 2

Multiple Choice Questions :

1. (d)	2. (d)	3. (d)	4. (b)
5. (a)	6. (a)	7. (a)	8. (b)
9. (d)	10. (c)	11. (a)	12. (b)
13. (c)	14. (d)	15. (c)	16. (b)
17. (a)	18. (a)	19. (b)	20. (a)
21. (d)	22. (d)	23. (c)	24. (d)
25. (b)	26. (b)	27. (a)	28. (b)
29. (c)	30. (d)	31. (a)	32. (b)
33. (d)	34. (d)	35. (b)	36. (c)
37. (c)	38. (d)	39. (d)	40. (a)
41. (b)	42. (d)	43. (a)	44. (c)
45. (b)	46. (d)	47. (b)	48. (a)
49. (d)	50. (d)	51. (d)	52. (c)
53. (b)	54. (b)	55. (a)	

More Than One Correct :

1. (a, b, c)	2. (a, c)	3. (a, d)
4. (a, b, c)	5. (a, d)	6. (b, c, d)
7. (a, c)	8. (a, b)	9. (b, c)
10. (a, d)	11. (a, c, d)	12. (a, b, c)

Fill in the Passage :

I. (1) electricity (2) magnetic effect (3) carrying (4) magnet (5) magnitude of current (6) increases (7) eastwards

II. (1) attracts (2) poles (3) north-south (4) opposite (5) repel (6) magnetic

III. (1) Concentric circles (2) centre (3) polarity (4) opposite (5) straight conductor (6) reversed

Passage Based Questions :

Passage:I

1. (c) 2. (b) 3. (d)

Passage:II

1. (d) 2. (c) 3. (c)

Passage:III

1. (a) 2. (d) 3. (b)

Assertion & Reason :

1. (e) In the case of metallic rod, the charge carries flow through whole of the cross section. Therefore, the magnetic field exists both inside as well as outside. However magnetic field inside the rod will go no decreasing as we go towards the axis.
2. (a)
3. (c) From equation $F = quB \sin\theta$. Force on moving charge will be maximum if direction of velocity of charge is perpendicular to direction of magnetic field (when $\theta = 90°$)
4. (a)
5. (a) Magnetic force is always perpendicular to the direction of motion of charged particle, i.e., work done on the charge particle moving on a circular path in magnetic field is zero.
6. (b) The wires are parallel to each other but the direction of current in it is in same direction so they attract each other. If the current in the wire is in opposite direction then wires repel each other. When the currents are in opposite directions, the magnetic forces are reversed and the wires repels each other
7. (d) When current flows through a solenoid, the currents in the various turns of the solenoid are parallel and in the same direction. Since the currents flowing through parallel wires in the same direction lead to force of attraction between them, the turns of the solenoid will also attract each other and as a result the solenoid tends to contract.
8. (c) In a conductor, the average velocity of electrons is zero. Hence no current flows through the conductor. Hence, no force acts on this conductor.

9. (b) The torque acting on a coil is given by,

$$\tau = NIAB \sin\theta$$

where θ is the angle between the plane of the coil and the direction of magnetic field. When θ = 90°, then τ = 0. The coil tries to orient itself in this position. Thus in equilibrium, the coil acquires a position, such that its plane makes an angle 90° with the direction of magnetic field.

10. (a) In case of the electric field of an electric dipole, the electric lines of force originate from positive charge and, end at negative charge. Since, isolated magnetic lines are closed continuous loops extending throughout the body of magnet, hence they from endless curves.

11. (c) Force acting on each pair of the opposite sides of the coil are eq

MULTIPLE MATCHING QUESTIONS :

1. A → r; B → p ; C → p; D → s

The force experienced by a coil in a magnetic field is given by $F = P_m \frac{\partial B}{\partial r}$, where $\frac{\partial B}{\partial r}$ is the increment of B along magnetic dipole moment of contour. You can write the expression for magnetic field due to solenoid at a general point and then differentiate it. From this information, you can have the results. Whether the force is attractive or repulsive can also be found by using the concept of nature of poles induced on the solenoid and coil.

The force comes out to be zero at centre and as we approach it from some outside point, its value increases.

For D: The coil first rotates to allign itself in such a manner so as to link the maximum flux and then the case would be same as that of C.

2. A → p; B → r ; C → s; D → s

Work done by magnetic force is zero. From work-energy theorem, its speed or kinetic-energy is constant.

3. A → r; B → p ; C → t; D → p

θ, the angle between $\vec{M}$ and $\vec{B}$ is zero, as both the vectors are along positive Z- direction.

HOTS SUBJECTIVE QUESTIONS :

1. Direction of magnetic field inside the loop is perpendicular to the plane of paper inward and direction of magnetic field outside the loop is perpendicular to the plane of paper outward.
2. The force experienced by a current-carrying conductor placed in a magnetic field is largest when the direction of current is at right-angles to the direction of the magnetic field.
3. Since the charged particles are deflected in opposite directions in the same magnetic field, we can say that they have opposite charges, may be electron and proton, for example.
4. The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south. The direction of magnetic field at a point directly above the wire is from south to north.
7. (i) In electric field, there is always a force on the moving electron opposite to the direction of field. Thus the force will be zero only if field is zero.

   (ii) In magnetic field, the force acting on a moving electron is F = q v B sin θ, it is zero if θ = 0° or 180° i.e., the electron is moving parallel to the direction of magnetic field.
8. When a charged particle is moving in a uniform magnetic field it experiences a force in a direction, perpendicular to its direction of motion. Due to which the speed of the charged particle remains unchanged and work done on it is zero, hence its kinetic energy remains same.
9. It assumes circular shape with its plane normal to the field to maximize flux, since for a given perimeter, a circle encloses greater area than any other shape.
10. If electron passing through a certain region does not suffer any deflection, then we are not sure that there is no magnetic field in that region. This is due to that electron suffers no force when it moves parallel or antiparallel to magnetic field. Thus the magnetic field may exist parallel or antiparallel to the direction of motion of electron.
11. Pure iron is not used for making permanent magnets because it cannot retain their magnetism for long time and used only for electromagnet since alloys of iron and steel have strongly magnetised and have a capacity to hold it for a longer time period, they are used for permanent magnets.

    Material used for permanent magnet–ALNICO. Formation of a permanent magnet electrically. Permanent magnets can be formed by placing a hard steel rod in the strong uniform magnetic field produced by the solenoid. Steels have the quality to retain its magnetism after switch off the solenoid current.

    Permanent magnets are used in

    (i) Galvanometer

    (ii) Ammeter.
12. To detect the presence of the magnetic field created by the current in a circular loop at the centre, one can draw the magnetic field lines with the help of compass needle. The magnetic field lines appear as a straight line at the centre and other lines appear in the same direction without the loop.

    Direction of field is given by the right hand thumb's rule.

    Right hand thumb rule. Hold the wire in your right hand with your extended thumb pointing in the direction of current. Your folded fingers will indicate the direction of magnetic field around the wire.
13. The strength of the magnetic field produced at the centre of a circular coil of radius r, having N turns and carrying a current, I, is given by

$$B = \frac{\mu_0 NI}{2r} \text{ testla}$$

Thus, the strength of a magnetic field in the coil is

(i) inversely proportional to the radius of the loop.

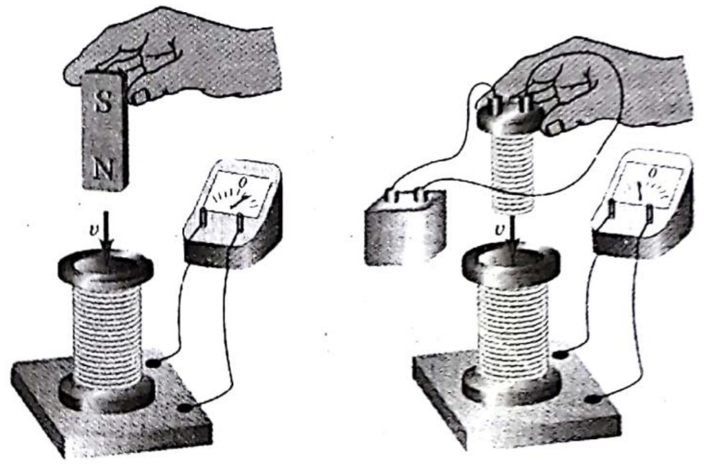
$$\left(B \propto \frac{1}{r}\right)$$

(ii) directly proportional to the number of turns. $(B \propto N)$

(iii) directly proportional to the current passing through it. $(B \propto I)$

14. Four times

chapter 7



ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

Introduction

We use generator or dynamo to produce electricity when the power supply disappears. They have a coil, called the armature, rotating in a magnetic field and convert the mechanical energy, i.e., the rotational kinetic energy, into the electrical energy. These electromechanical devices are based on the principle of what is called the electromagnetic induction. It is the phenomenon is which a changing magnetic field produces an induced emf and current. This chapter is all about this phenomenon and the alternating current.

The alternating currents play an important role in the present day technology and industry. The transmission of electrical power over the long distances becomes very much easier and more economical with the alternating currents than the direct currents. The circuits used in the modern communication systems, including the radio and television, computer systems, and so on, make an extensive use of the alternating currents. The alternating currents are involved in the many life processes. The electrocardiography, i.e., the detection and study of alternating currents induced in the surrounding tissues due to the heart beating, provides a valuable information about the health and pathology of heart. The electroencepnalograms, being the recordings of alternating currents in the brain, provide a vital information regarding the functioning of brain.

ELECTROMAGNETIC INDUCTION

In the early 1800s, the only current-producing devices were voltaic cells, which produced small currents by dissolving metals in acids. These were the forerunners of our present-day batteries. The question arose as to whether electricity could be produced from magnetism. The answer was provided in 1831 by two physicists, Michael Faraday in England and Joseph Henry in the United States—each working without knowledge of the other. Their discovery changed the world by making electricity commonplace—powering industries by day and lighting up cities at night.

Faraday and Henry both discovered that electric current could be produced in a wire simply by moving a magnet into or out of a coil of wire. (Figure 7.1). No battery or other voltage source was needed—only the motion of a magnet in a wire loop. They discovered that voltage is caused, or *induced,* by the relative motion between a wire and a magnetic field. Whether the magnetic field moves near a stationary conductor or vice versa, voltage is induced either way (Figure 7.2).

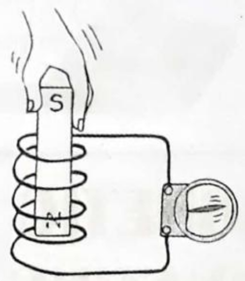


Fig. 7.1. When the magnet is plunged into the coil, charges in the coil are set in motion, and voltage is induced in the coil.

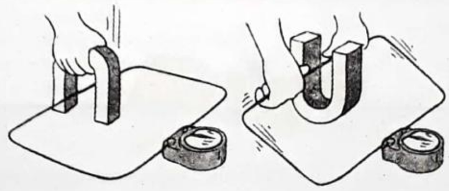


Fig. 7.2. Voltage is induced in the wire loop whether the magnetic field moves past the wire or the wire moves through the magnetic field.

The greater the number of loops of wire moving in a magnetic field, the greater the induced voltage (Figure 7.3). Pushing a magnet into a coil with twice as many loops induces twice as much voltage; Pushing into a coil with ten times as many loops induces ten times as much voltage; and so on. It may seem that we get something (energy) for nothing simply by increasing the number of loops in a coil of wire, but we don't: We find that it is more difficult to push the magnet into a coil made up of more loops. This is because the induced voltage produces a current, which makes an electromagnet, which repels the magnet in our hand. So we must do more work against this "back force" to induce more voltage (Figure 7.4).

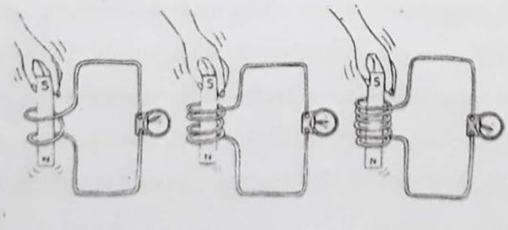


Fig. 7.3, *When a magnet is plunged into a coil with twice as many loops as another, twice as much voltage is induced. If the magnet is plunged into a coil with three times as many loops, three times as much voltage is induced.*

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Fig. 7.4. It is more difficult to push the magnet into a coil with many loops because the magnetic field of each current loop resists the motion of the magnet.

The amount of voltage induced depends on how fast the magnetic field lines are entering or leaving the coil. Very slow motion produces hardly any voltage at all. Rapid motion induces a greater voltage. This phenomenon of inducing voltage by changing the magnetic field in a coil of wire is called **electromagnetic induction.**

FARADAY'S EXPERIMENT

In 1831, Michael Faraday carried out numerous experiments in his attempt to prove that electricity could be generated from magnetism. Within the course of a few weeks, the great experimentalist not only had clearly demonstrated this phenomenon, now known as electromagnetic induction, but also had developed a good conception of the processes involved.

When a bar magnet is thrust into a coil connected to an electric circuit, a current is caused to flow in the circuit to which the coil is attached. If the magnet is withdrawn, the direction of the current is reversed. Such currents are called induced currents.

The size of the current depends on how fast the magnet moves in or out of the coil, and the number of loops in the coil.

The phenomenon of inducing a current by changing the magnetic field in a coil of wire is known as electromagnetic induction. This phenomenon underpins the design of all electric generators.

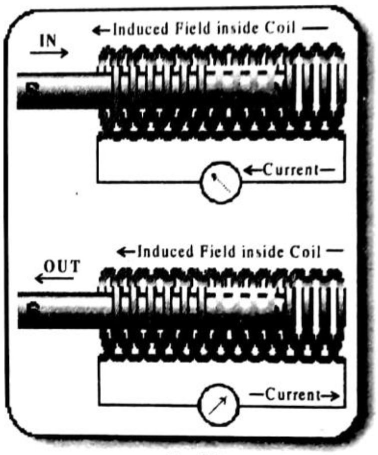
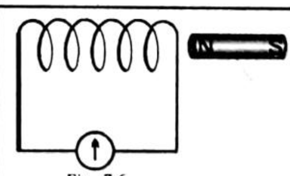
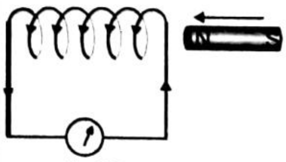


Fig. 7.5

FARADAY'S EXPERIMENTS AND OBSERVATION :

Experiment	Observation	
1. Place a magnet near a conducting loop with a galvanometer in the circuit	No current flows through the galvanometer.	 *Fig. 7.6*
2. Move the magnet towards the loop.	The galvanometer register a current.	 *Fig. 7.7*

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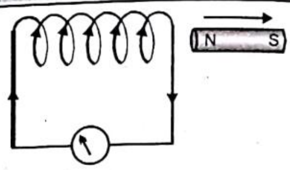
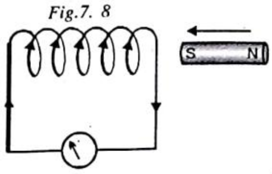
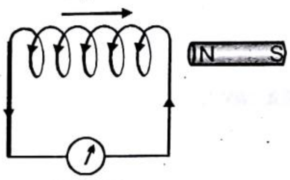
3. Reverse the direction of motion of the magnet	The galvanometer deflection reverses	 Fig.7. 8
4. Reverse the polarity of the magnet and move the magnet towards the loop	The galvanometer deflection reverses	 Fig. 7.9
5. Keep magnet fixed and move the coil towards the magnet	The galvanometer register a current.	 Fig. 7.10
6. Increases the speed of the magnet	The deflection increases	
7. Increase the strength of the magnet	The deflection increases	
8. Increase the diameter of the coil	The deflection increases	
9. Fix the speed of the magnet but repeat the experiment with the magnet closer to the coil.	The deflection increases	
10. Move the magnet at an angle to the plane of the coil.	Deflection decreases Deflection is maximum when the magnet moves perpendicular to the plane of the coil. Deflection is zero when the magnet moves parallel to the plane of the coil.	
11. Increase the number of turns of the coil	Magnitude of current increases.	

COIL-COIL EXPERIMENTS

A coil known as primary (P) is connected in series with the source battery (B) and a tap key (K). Another coil called as secondary (S) is placed closed to the primary coil but not perpendicular to one another.

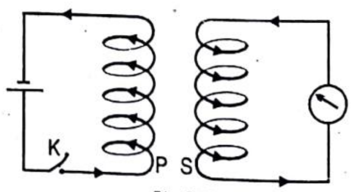


Fig. 7.11

The following observations are made

(i) When the key is pressed, the galvanometer shows a momentary deflection.

(ii) When the current becomes steady i.e. key is kept pressed, the deflection is zero.

(iii) When the key is released, the galvanometer again shows a momentary deflection, but now in the opposite direction.

These observations reveal that as long as there is a change in current in P, an e.m.f. is induced in S. This phenomenon in which an e.m.f. is induced in a coil due to a varying current in a neighbouring coil is called mutual induction.

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It can also be seen that on keeping K pressed i.e. steady current flowing through P, but on moving S away or towards P, the galvanometer shows deflection, in either case in the opposite directions.

These observations show that an e.m.f is induced in the coil, whenever there is a relative motion between the magnet and the coil.

MAGNETIC FLUX

- To represent magnetic lines of forces quantitatively magnetic flux is used.

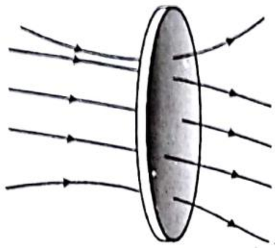

Fig. 7.12 The magnetic flux for a surface is proportional to the number of field lines intersecting the surface.

If the magnetic field $\vec{B}$ makes an angle θ with the normal to the surface as shown in figure. then the normal component of the field is B cos θ and in this case,

the magnetic flux is given by $\phi = BA\cos\theta$ or $\phi = \vec{B} \cdot \vec{A}$

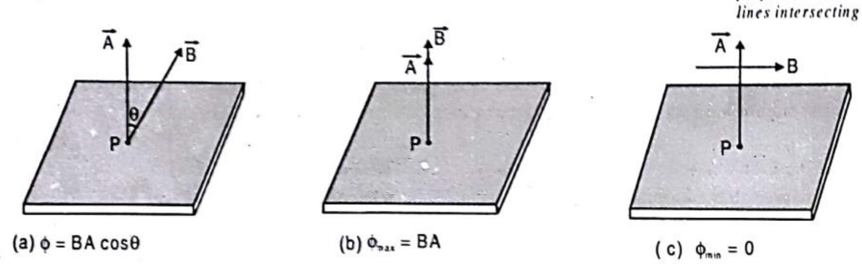

Fig. 7.13

So, magnetic flux linked with a closed surface may be defined as the product of the surface area and the normal component of the magnetic field acting on that area. It may also defined as the dot or scalar product of magnetic field and surface area.

Physically it represents total lines of induction passing through a given area.

Positive and negative flux

In case of a body present in a field, either uniform or non-uniform, outward flux is taken to be positive while inward negative,

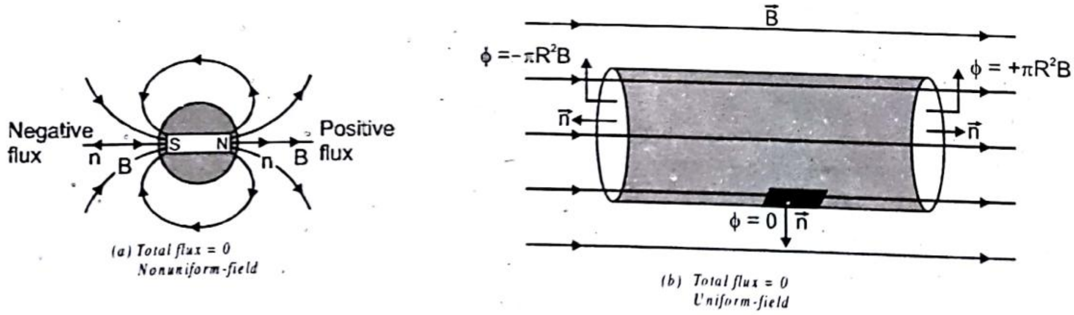

Fig. 7.14

If the normal drawn on the surface is in the direction of the field, then the flux is taken as positive.

In this case, θ is 0°. or θ < 90° then the flux is taken as positive.

If the normal on the surface is opposite to the direction of the field, then θ = 180°.

In this case, the magnetic flux is taken as negative.

Magnetic flux density, $B = \dfrac{\phi}{A}$

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Different ways which can vary the magnetic flux

Magnetic flux in planar area $\vec{A}$ due to an uniform magnetic field $\vec{B}$

$$\phi = B\,A\cos\theta$$

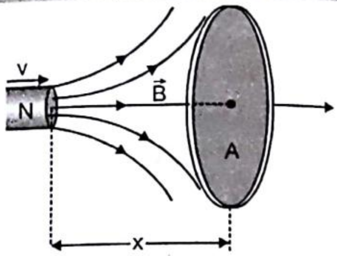

Fig. 7.15 Flux changes as B changes

So flux linked with a circuit will change only if field B, area A, orientation θ or any combination of these changes.

(1) By varying the magnetic field $\vec{B}$ with time

Due to motion of magnet B will change with time.

Or if magnetic field produced due to current carrying loop then due to change in current change in B will occur with time.

(2) By varying the area of the conducting loop $\vec{A}$ with time

The second method of inducing a change in flux is to vary the area of the conducting loop with time.

(a) Change in Shape of the loop : Consider a square loop of side "a" placed perpendicular to a uniform and steady magnetic field B. Suppose the square loop transforms into a circular loop of the same circumference.

Initial area of the loop = a^2

The initial flux through the loop $\phi_i = Ba^2$

The final radius of the circular loop $r = \dfrac{4a}{2\pi} = \dfrac{2a}{\pi}$

The final flux through the loop $\phi_f = B\pi r^2 = \dfrac{4Ba^2}{\pi}$

The net change in flux $(\phi_f - \phi_i) = Ba^2\left(\dfrac{4}{\pi} - 1\right)$

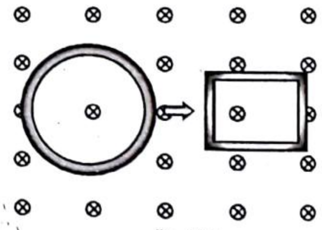

Fig. 7.16

(b) Rod Translating in a Π Circuit : Consider a U shaped or a Π shaped conducting wire placed with its plane perpendicular to a uniform magnetic field $\vec{B}$.

A conducting rod is placed on this wire so as to short the two arms of the U as shown in figure.

Let the distance between the two arms of the U be ℓ. We now have a closed conducting loop resting in a uniform magnetic field with one of the sides of the loop free to move.

Now suppose the rod translates to the right with a speed v. Then with time, the area enclosed by this loop will keep increasing and with it the flux through the loop will also change.

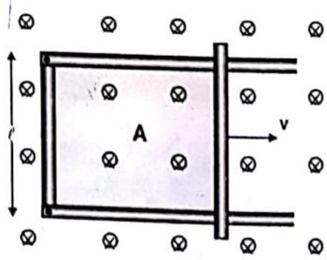

Fig. 7.17 Flux changes as A changes

(3) Loop entering or leaving a finite region of magnetic field

(a) Rectangular loop passing through magnetic field : Method for creating a loop with a time varying area is to have a closed loop enter or leave a region of magnetic field. Here the actual area of the loop does not change with time. However, the effective area of the loop through which magnetic field lines pass, varies with time.

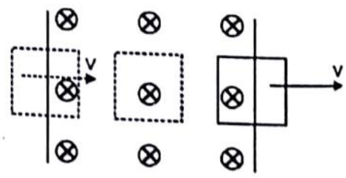

Fig. 7.18

(b) Loop rotating in and out of a finite region of magnetic field : Consider a semicircular loop placed at the edge of a magnetic field. The loop rotates with an angular velocity ω about an axis perpendicular to the plane of the paper and passing through O. As the loop rotates, the area immersed in the magnetic field varies with time.

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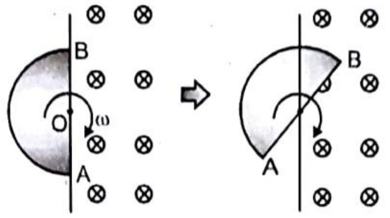
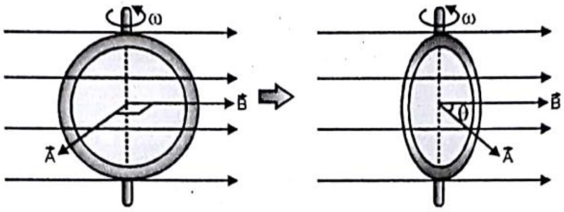


Fig. 7.19

(4) Effect of time varying angle between the area vector and the magnetic field vector

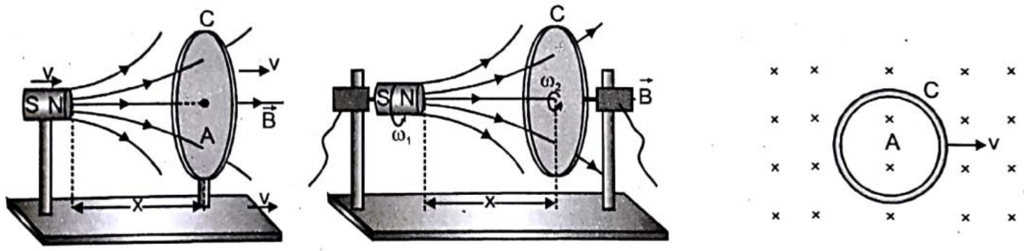
Consider a circular loop placed in an uniform magnetic field $\vec{B}$ such that the plane of the loop is initially parallel to the magnetic field. Let us now rotate the loop about its diameter with a constant angular velocity ω with time and consequently the flux through the loop also varies ($\phi = B\,A\cos\theta$) Since θ varies so φ also varies.



(a) Fig. 7.20 (b)

The flux linked with a loop C will not change with time

If B, A and θ does not change with time, then $\phi = BA\cos\theta = B(N\pi R^2)\cos 0 = N\pi R^2 B = \text{const.}$



(a) (b) (c)

Fig. 7.21

FARADAY'S LAWS OF ELECTRO-MAGNETIC INDUCTION

Whenever there is change in the magnetic flux associated with a circuit, an e.m.f. is induced in the circuit.

The magnitude of the induced e.m.f. (e) is directly proportional to the time rate of change of the magnetic flux through the circuit.

$$e \propto \frac{\Delta\phi}{\Delta t} \quad \text{or} \quad e = k\frac{\Delta\phi}{\Delta t}$$

k = const. of proportionality depending upon the system of units used.

In the S.I. system, e.m.f. 'e' is measured in volt and $\frac{\Delta\phi}{\Delta t}$ in Wb/sec.

In MKS or SI system, these units are so chosen that k = 1, and 1 Volt = 1 Wb/sec

Faraday's laws do not give the direction of the induced e.m.f. or current.

Induced current or e.m.f. lasts only for the time for which the magnetic flux is changing.

If the coil has N turns, then the e.m.f will be induced in each turn and the e.m.f.'s of all the turns will be added up. If the turns of coil are very close to each other, the magnetic flux passing through each turn will be same.

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So, the induced e.m.f in the whole coil $e = N\frac{\Delta\phi}{\Delta t}$

$N\phi$ = number of 'flux linkages' in the coil.

FLEMING'S RIGHT HAND RULE

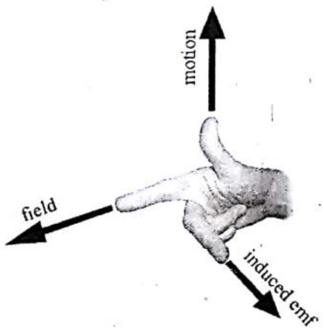

Fig. 7.22

Fleming's right hand rule gives the direction of the induced e.m.f. and current in a straight conductor moving perpendicular to the direction of magnetic field.

Statement : Stretch out the thumb, fore finger and middle finger of the right hand mutually perpendicular to each other. If the fore finger points in the direction of magnetic field, the thumb in the direction of motion of the conductor, then the middle finger will point out the direction of induced current or induced e.m.f.

LENZ'S LAW

The direction of the induced current is given by Lenz's law.

The direction of the induced current is such that it oppose the change in the magnetic flux that causes the induced current or e.m.f. i.e. induced current tries to maintain flux.

On combining Lenz's law with Faraday's laws $e = -\frac{\Delta\phi}{\Delta t}$

–ve sign indicating that the induced e.m.f. opposes the change in the magnetic flux.

The Lenz's Law is consistent with the law of conservation of energy.

The induced e.m.f. is produced at the cost of mechanical work done by an external agent in the magnet and coil experiment.

When the N-pole of the magnet is moved towards the coil, the face of the coil facing the north pole acts like a north pole. (This can be found by Flemings' Right hand Rule).

As the magnet is moved towards the coil, the magnetic flux linked with the coil increases.

To oppose this increase in flux, e.m.f. induced in the coil has to be in such a direction as to reduce the increase in flux. The external agent has to do some work against this force of repulsion between the two N-pole. This is converted into electrical energy as shown in figure.

Similarly if the magnet with its N-pole is moved away from the coil, then the face of the coil acts like a South pole and hence the flux linked with the coil tends to decrease. The induced current or e.m.f. must now be in a direction so as to increase the flux as shown in figure.

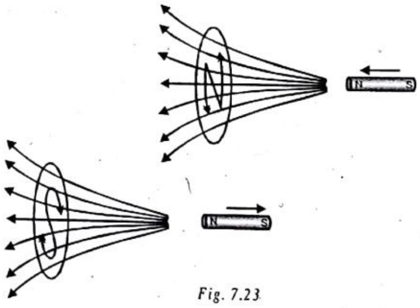

Fig. 7.23

The external agent has to do work against this force of attraction between the N and S poles and this is converted into electrical energy.

If suppose, on moving the N pole of the magnet towards the coil, a south polarity is induced on the face of the coil, then the magnet would be attracted to the coil, and there would be a continuous increase in magnetic flux linked with the coil leading to a continuous increase in e.m.f. without any expenditure of energy and this would violate the principle of conservation of energy.

CHECK Point

- **If your metal car moves over a wide, closed loop of wire embedded in a road surface, will the magnetic field of the earth within the loop be altered? Will this produce a current pulse? Can you think of a practical application for this at a traffic intersection?**

SOLUTION

Yes, our metal cars moving over a wide, closed loop of wire embedded in a road surface, change the magnetic field of the earth within the loop.

This change in the magnetic field induces currents in the wire loops and a current pulse is produced.

At a traffic intersection, the colour of the traffic light changes as a result of these current pulses.

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Knowledge ENHANCER

Determination of the direction of the induced current in a circuit (Using Lenz's Law)

Lenz's law : "when the magnetic flux through a loop changes, a current is induced in the loop such that the magnetic field due to the induced current opposes the change in the magnetic flux through the loop".

The above rule can be systematically applied as follows to determine the direction of induced currents.

(A) Identify the loop in which the induced current is to be determined

(b) Determine the direction of the magnetic field in this loop (i.e., in or out of the loop)

(c) The direction of flux is the same as the direction of the magnetic field
Determine if the flux through the loop is increasing or decreasing
(due to change in area, or change in B)

(d) Choose the appropriate current in the loop that will oppose the change in flux i.e.,

a. If the flux is into the paper and increasing, the flux due to the induced current should be out of the paper.

b. If the flux into the paper and decreasing, the flux due to the induced current should be into the paper.

c. If the flux is out of the paper and increasing, the flux due to the induced current should be into the paper.

d. If the flux is out of the paper and decreasing, the flux due to induced current should be out of the paper.
The above description is the physical interpretation of Lenz's law.

SIGN CONVENTION FOR INDUCED EMF

Positive Induced EMF

When the magnetic flux ϕ_m through a circuit C decreases with the increase of time t so that the time rate of change, i.e., $\frac{d\phi_m}{dt}$, is negative, the induced e.m.f. e is positive. In this case, the induced magnetic field $\vec{B}'$ of the induced current i is in the direction of the applied, or inducing, magnetic filed $\vec{B}$, as shown.

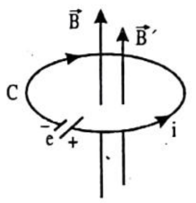

Fig. 7.24

NEGATIVE INDUCED EMF

When the magnetic flux ϕ_m through a circuit C increases with the increase of time t so that the time rate of change, i.e., $\frac{d\phi_m}{dt}$, is positive, the induced e.m.f. e is negative. In this case, the induced magnetic field $\vec{B}'$ of the induced current i is in the direction opposite to that of the applied, or inducing, magnetic field $\vec{B}$, as shown.

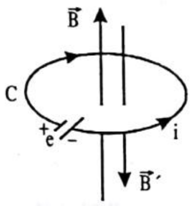

Fig. 7.25

ILLUSTRATION 7.1

A cir cular wire loop of radius 10 cm lies in a uniform magnetic field $\vec{B}$ of 100 T, acting perpendicular to the plane of loop. If T, acting perpendicular to the plane of loop. If this loop is deformed to take a square shape in the same plane in the time 0.1 s, what will be the average e.m.f. induced in the loop?

SOLUTION :

The given circular loop of radius 0.1 m has the circumferential length $(2\pi \times 0.1)$ m and area

$A_1 = \pi\ (0.1)^2 = \pi.\ 10^{-2}\ m^2$

When this loop is deformed into the square loop, it's linear size will be

$$A_2 = \left(\frac{2\pi \times 0.1}{4}\right)^2$$

$$= \frac{\pi^2 \times 10^{-2}}{4} m^2$$

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The decrease in the area of loop is

$$\Delta A = A_1 - A_2, = \left(\frac{4-\pi}{4}\right)\times\pi\times10^{-2}\,m^2$$

and the decrease in the magnetic flux through the loop becomes

$\Delta\phi_m = B\ (\Delta A)$

$$= 100\times\left(\frac{4-\pi}{4}\right)\times\pi\times10^{-2}\,wb$$

Finally, the average e.m.f. induced in the loop is of magnitude

$$e = \frac{\Delta\phi_m}{\Delta t} = \frac{100\times(4-\pi)\times\pi\times10^{-2}}{4\times0.1} = 6.75V$$

SELF INDUCTION

The property of a coil by virtue of which the coil opposes any change in the strength of the current flowing through it, by inducing an e.m.f. in itself is called self inductance.

When a current I flows through a coil, the magnetic flux ϕ linked with the coil is $\phi = LI$, where L is coefficient of self induction or self inductance of the coil. On differentiating, we get

$$\frac{d\phi}{dt} = L\frac{dI}{dt} = -e$$

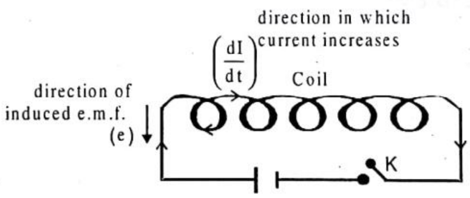

Fig. 7.26

If $dI/dt = 1$; $L = -e$. Hence self inductance of a coil is equal to e.m.f. induced in the coil when rate of change of current through the same coil is unity. Coefficient of self induction of a coil is also defined as the magnetic flux linked with a coil when 1 ampere current flows through the same coil. The value of L depends on geometry of the coil and is given by $L = \frac{\mu_0 N^2 A}{\ell}$.

Where ℓ is length of the coil (solenoid), N is total number of turns of solenoid and A is area of cross section of the solenoid. The S.I. unit of L is henry. Coefficient of self induction of a coil is said to be one henry when a current change at the rate of 1 ampere/sec. in the coil induces an e.m.f. of one volt in the coil.

ILLUSTRATION 7.2

A conducting rectangular loop of breadth, l, mass m and resistance R is placed vertically, as shown, partly in and partly out of a uniform magnetic field $\vec{B}$ which acts in the horizontal direction. What should be the velocity v by which the loop is pushed downwards so that is may continue to fall without any acceleration?

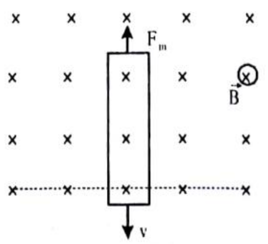

Fig. 7.27

SOLUTION:

When the rectangular loop is pushed downwards with the velocity v in the magnetic field $\vec{B}$, the magnetic flux through it decreases and hence, the e.m.f. induced in the loop will be

$$e = vBl$$

and the current induced in the loop will be

$$i = \frac{e}{R} = \frac{vBl}{R}$$

which flows in the clockwise direction so as to counterbalance the decrease in magnetic flux, according to the Lenz's law. The net magnetic force on the loop, acting vertically upwards on the upper side, according to the ***'Fleming's Left-Hand Rule'***,

is $F_m = ilB = \dfrac{vB^2l^2}{R}$

which balances the weight mg of loop and consequently, the loop falls without any acceleration. Thus,

$$mg = \frac{vB^2l^2}{B^2l^2}$$

$$\Rightarrow v = \frac{mgR}{B^2l^2}$$

Keep in memory

1. *Energy stored in a coil* $= \frac{1}{2}\text{Li}^2$ *where* $\mathcal{L}$ *is the self-inductance and i the current flowing through the inductor. The energy stored in the magnetic field of the coil.*
2. *The self inductance is a measure of the coil to oppose the flow of current through it. The role of self-inductance in an electrical circuit is the same as that of the inertia in mechanics. Therefore it is called electrical inertia.*
3. *The magnetic energy density (energy stored per unit volume) in a solenoid* $= \dfrac{B^2}{2\mu_0}$.

- $$E = \frac{1}{2}Li^2 = \frac{1}{2}(\mu_0 n^2 A\ell)\left(\frac{B}{\mu_0 n}\right)^2$$

$$= \left(\frac{B^2}{2\mu_0}\right)A\ell = \left(\frac{B^2}{2\mu_0}\right) \times \text{Volume}$$

MUTUAL INDUCTION

The mutual induction is another kind of electromagnetic induction in which a changing current i_p in one circuit called the primary, induces an emf e_s and , in turn, may induce a current i_s in another nearby circuit, called the secondary S. Out of the two circuits involved in the mutual induction process, any one can be taken as primary, or secondary. However, the two circuits constitute a mutual inductor.

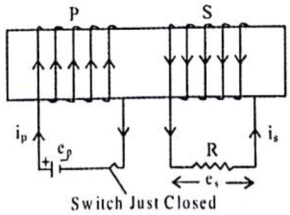

Fig. 7.28

When a constant, or variable, current i flows through the primary P, then the total magnetic flux through each turn of the secondary S is Φ_{ms} and the total magnetic flux, or flux linkage, through all the N_s turns, assumed identical, of secondary S is

$$N_s \Phi_{ms} \propto i_p$$
$$= Mi_p$$
$$\Rightarrow \quad M = \frac{N_s \phi_{ms}}{i_p}$$

where the constant of proportionatity M is a positive physical parameter, called the mutual inductance, or coefficient of mutual induction, of the two circuits. Evidently, M is total magnetic flux, or flux linkage, through the secondary per unit current in the primary.

If the primary current i_p is variable, the induced emf in the secondary S is given by

$$e_s = -\frac{d}{dt}(Ns\,\phi_{ms}) = -\frac{d}{dt}(M\,i_p)$$

$$= -M\frac{di_p}{dt}, \qquad M = -\frac{e_s}{\left(\frac{di_p}{dt}\right)}$$

which means that the mutual inductance M is the induced emf in the secondary per unit rate of change of current in the primary. The mutual inductance M depends on the geometry of two circuits and their proximity. It's SI unit is the same as that of the self inductance L, i.e., 1 henry.

UNIT OF INDUCTANCE : Henry(H)

COMBINATIONS OF INDUCTANCES

Series Combination

Let us consider a series combination of two inductors of inductances L_1 and L_2, with the coefficient of coupling $k = 0$. Let i be the instantaneous current through them and di/dt be the rate of change of current i.

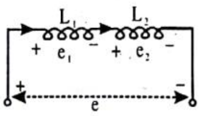

Fig. 7.29

Then, the total potential difference across the two inductors in series, taken together, is

$$e = e_1 + e_2$$

$$\Rightarrow \quad L\frac{di}{dt} = L_1\frac{di}{dt} + L_2\frac{di}{dt}$$

where e_1 and e_2 are the potential differences across the two inductors, taken separately, and L is the equivalent inductance of the series combination. Simplifying the above equation, we have

$$L = L_1 + L_2$$

Parallel Combination

Let us now consider the two inductors of inductances $L_1$and L_2 in parallel, with the coefficient of coupling $k = 0$. Let i be instantaneous current fed to the parallel combination and di/dt be the rate of change of current i.

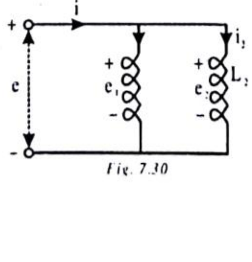

Fig. 7.30

The total potential difference across the two inductors in parallel, taken together, is equal to the potential difference across each one of them, taken separately.

$$e = e_1 = e_2$$

However, the current divides into i_1 and i_2, as shown, and therefore,

$$i = i_1 + i_2$$

$$\Rightarrow \frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt}$$

$$\Rightarrow \frac{e}{L} = \frac{e_1}{L_1} + \frac{e_2}{L_2}$$

$$\Rightarrow \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

ELECTRIC GENERATOR

The large generators present in hydroelectric power plants depend on magnets for their operation. They convert the kinetic anergy in moving water into electricity. Generators in fossil-fueled and nuclear-fueled power plants harness the kinetic energy in moving steam in the same way.

Electrical current can be generated by moving a metal wire through a magnetic field. This applies both to alternating current (AC) and direct current (DC) electricity.

When a coil of conducting wire is rotated in a magnetic field, electromagnetic induction results in an induced current flowing through the loop. In this way, mechanical energy is converted to electrical energy. The device is called a generator or dynamo. The generator will produce an electromotive force that will vary sinusoidally with the angle made by the coil and the applied field. Thus the direction of the current will vary and the current so produced is called an alternating current. A better name for the device is alternator.

Note that this is analogous to an electric motor: the motor converts electrical energy into mechanical energy, while the alternator converts mechanical energy into electrical energy. The alternator does not create electricity out of nothing.

Working of generator : An electric generator, consists of a rotating rectangular coil ABCD placed between the two poles of a permanent magnet. The two ends of this coil are connected to the two rings R_1 and R_2. The inner side of these rings are made insulated. The two conducting stationary brushes B_1 and B_2 are kept pressed separately on the rings R_1 and R_2, respectively. The two rings R_1 and R_2 are internally attached to an axle. The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field.

Outer ends of the two brushes are connected to the galvanometer to show the flow of current in the given external circuit. When the axle attached to the two rings is rotated such that the arm AB moves up (and the arm CD moves down) in the magnetic field produced by the permanent magnet. Let us say the coil ABCD is rotated clockwise in the arrangement. By applying Fleming's right-hand rule, the induced currents are set up in these arms along the directions AB and CD. Thus an induced current flows in the direction ABCD. If there are larger numbers of turns in the coil, the current generated in each turn adds up to give a large current through the coil. This means that the current in the external circuit flows from B_2 to B_1.

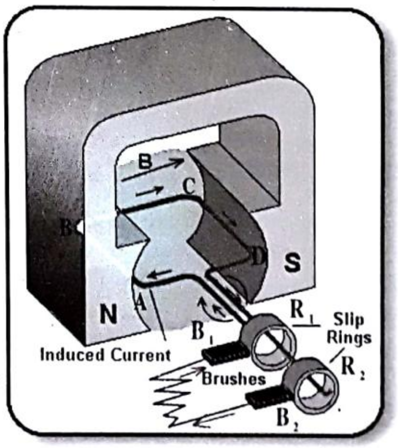

Fig. 7.31 : AC generator

After half a rotation, arm CD starts moving up and AB moving down. As a result, the directions of the induced currents in both the arms change, giving rise to the net induced current in the direction DCBA.

The current in the external circuit now flows from B_1 to B_2. Thus after every half rotation the polarity of the current in the respective arms changes. Such a current, which changes direction after equal intervals of time, is called an alternating current (abbreviated as AC). This device is called an AC generator.

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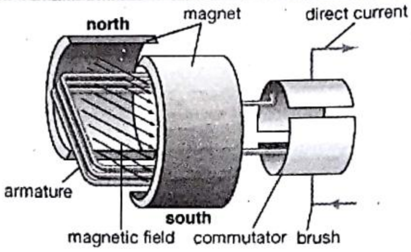


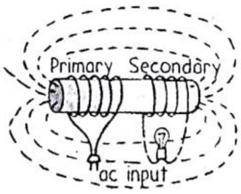
Fig. 7.32 : Split-ring type commutator.

To get a direct current (DC, which does not change its direction with time), a split-ring type commutator must be used. With this arrangement, one brush is at all times in contact with the arm moving up in the field, while the other is in contact with the arm moving down.

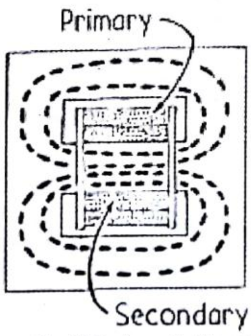
The difference between the direct and alternating currents is that the direct current always flows in one direction, whereas the alternating current reverses its direction periodically. Most power stations constructed these days produce AC. In India, the AC changes direction after every 1/100 second, that is, the frequency of AC is 50 Hz. An important advantage of AC over DC is that electric power can be transmitted over long distances without much loss of energy.

TRANSFORMER

When changes in the magnetic field of a current-carrying coil of wire are intercepted by a second coil of wire, voltage is induced in the second coil. This is the principle of the **transformer**—a simple electromagneic-induction device consisting of an input coil of wire (the primary) and an output coil of wire (the secondary). The coils need not physically touch each other, but they are normally wound on a comman iron core so that the magnetic field of the primary passes through the secondary. The primary is powered by an AC voltage source, and the secondary is connected to some external circuit. Changes in the primary current produce changes in its magnetic field. These changes extend to the secondary, and by electromagnetic induction, voltage is induced in the secondary. If the number of turns of wire in both coils is the same, voltage input and voltage output will be the same. Nothing is gained. But, if the secondary has more turns than the primary, then greater voltage will be induced in the secondary. This is a *step-up transformer.* If the secondary has fewer turns than the primary, the AC voltage induced in the secondary will be lower than that in the primary. This is a *step-down transformer.*



7.33 : A simple transformer.



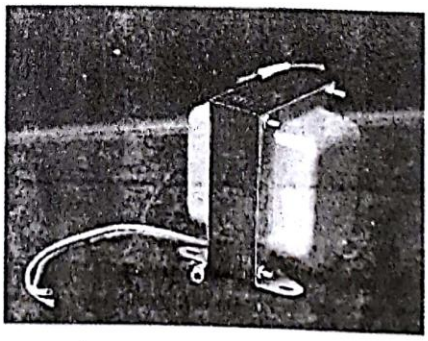


Fig. 7.34 : A practical transformer. The iron coil guides the changing magnetic field lines.

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The relationship between primary and secondary voltages relative to the number of turns is

$$\frac{\text{Primary voltage}}{\text{Number of primary turns}} = \frac{\text{Secondary voltage}}{\text{Number of secondary turns}}$$

It might seem that we get something for nothing with a transformer that steps up the voltage, but we don't. When voltage is stepped up, current in the secondary is less than in the primary. The transformer actually transfers energy from one coil to the other. The rate of transferring energy is *power*. The power used in the secondary is supplied by the primary. The primary gives no more than the secondary uses, in accord with the law of energy conservation. If the slight power losses due to heating of the core are neglected, then

Power into primary = power out of secondary

Electric power is equal to the product of voltage and current, so we can say that

$$(\text{Voltage} \times \text{current})_{\text{primary}} = (\text{voltage} \times \text{current})_{\text{secondary}}$$

The ease with which voltages can be stepped up or down with a transformer is the principle reason that most electric power is AC rather than DC.

Fig. 7.35 Voltage generated in power stations is stepped up with transformers prior to being transferred across country by overhead cables. Then other transformers reduce the voltage before supplying it to homes, offices, and factories.

ENERGY LOSSES IN GENERATORS AND MOTORS

Copper loss, or Joule-Heating Loss

This loss arises due to the ***'Joule Heating'*** of coils, carrying the electric currents.

Iron loss, or Eddy-Current loss

This loss is associated with the eddy currents, i.e., currents of circulating nature, induced in the iron cores and can be minimised by doing the lamination of cores.

Hysteresis loss

This loss is associated with the magnetisation of ferromagnetic cores and can be minimised by using the ferromagnetics, having the thin hysteresis loops, e.g., solt iron.

Magnetic Flux leakage

The magnetic flux leakage from the current-carrying coils amounts to the loss of energy.

Mechanical loss

This loss is due to the friction at the bearings of moving parts, air resistance, etc.

CHECK Point

- **Two separate but similar coils of wire are moutned close to each other, as shown below. The first coil is connected to a battery and has a direct current flowing through it. The second coil is connected to a galvanometer. How does the galvanometer respond when the switch int he first circuit is closed? After being closed when the switch is opened?**

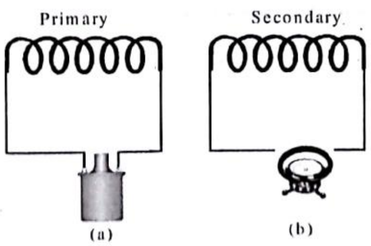

Fig. 7.36

SOLUTION

When the switch in the first circuit is closed, the current in the coil grows from zero to a maximum value. Correspondingly, a magnetic field is generated by the current in the second coil, which increases with the current. This increasing magnetic field induces a voltage in the second coil and a current flows in this coil. Thus, the galvanometer deflects in one direction from zero to a maximum value.

When the switch in the first coil is closed, the current increases from zero and reaches to a maximum steady value after a long time which depends on the resistance of the conducting wire and the inductance of the coil.

The switch can be opened after the current reaches a steady value. In this case, the current will tend to zero from the steady maximum value and the galvanometer will show deflection in the opposite direction.

ILLUSTRATION 7.3

A lossless transformer steps down 220 V to 22 V and operates a device having an impedance of 220 Ω. What is the primary current ?

SOLUTION:

In the lossless transformer, we are given that

$$V_P = 220\,V, V_S = 22\,V, I_S = \frac{22}{220} = 0.1A$$

and hence, $\frac{V_S}{V_P} = \frac{I_P}{I_S} \Rightarrow \frac{22}{220} = \frac{I_P}{0.1} \Rightarrow I_P = 0.01A$

ILLUSTRATION 7.4

In a transformer, the primary and secondary have 1000 and 3000 turns, respectively. If the primary is connected across an ac source of 80V, then what will be the voltage across each turn of the secondary.

SOLUTION:

In the transformer, we have

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \Rightarrow \frac{V_S}{80} = \frac{3000}{1000} \Rightarrow V_S = 240\,V$$

and then, the voltage across each turn of secondary becomes

$$\frac{V_S}{N_S} = \frac{240}{3,000} = 0.08\,V$$

ILLUSTRATION 7.5

A transformer is used to step-down a voltage from 220 V to 11V. If the primary and secondary currents are 5A and 90A, respectively, what is the efficiency of transformer?

SOLUTION:

The efficiency of transformer is

$$\eta = \frac{V_S I_S}{V_P I_P} \times 100\% = \frac{11 \times 90}{220 \times 5} \times 100\% = 90\%$$

EDDY CURRENTS (FOUCAULT CURRENTS)

The induced circulating currents produced in a metal itself due to change in magnetic flux linked with the metal are called eddy currents.

These currents were discovered by Foucault, so they are also known as Foucault Currents.

The direction of eddy currents is given by Lenz's law.

Eddy currents produced in a metallic block moving in a non-uniform magnetic field are shown in fig. 7.37.

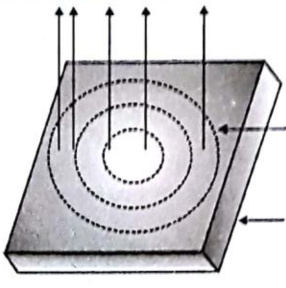

Fig. 7.37

Knowledge ENHANCER

Demonstration of Eddy Currents

Jumping Disc : An aluminium disc is placed over the core of an electro-magnet. When the circuit is closed i.e., alternating current flows in the circuit, the disc jumps up to a certain height.

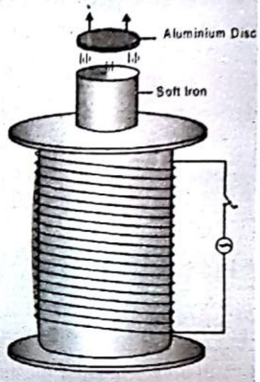

Fig. 7.38

When the current through the solenoid increases, the magnetic flux along the axis of the solenoid increases. Consequently, the magnetic flux linked with the disc also increases. Due to the change in magnetic flux, induced currents (i.e. eddy currents) are produced in the disc and it is slightly magnetised. If the upper face of the core of the electromagnet acquires north polarity, then according to Lenz's law, the lower face of the disc will also acquire North polarity. Due to the force of repulsion between the lower face (N-pole) of the disc and upper face (N-pole) of the core of the electro-magnet, the disc jumps upto a certain height.

ALTERNATING CURRENT (A.C.)

An alternating current is one which periodically changes in magnitude and direction. It increases from zero to a maximum value, then decreases to zero and reverses in direction, increases to a maximum in this direction and then decreases to zero.

The alternating currents change both in magnitude and direction periodically. They have the various different waveforms, or waveshapes, e.g., sinusoidal, square, triangualr, sawtoothed, and so on, depending on their applications. The alternating currents, in the normal use, have the sinusoidal waveform and represented analytically as

$$i = I_0 \sin(\omega t)$$

where i is the instantaneous value, I_0 is the peak value, or amplitude, $\omega = 2\pi/T = 2\pi f$ is the angular frequency, T being the time period and f being the frequency, and ωt is the phase angle.

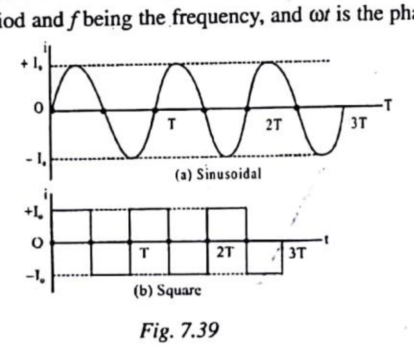

Fig. 7.39

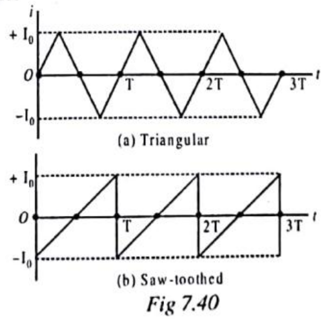

Fig 7.40

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The alternating currents are generated in the circuits energised by the sources of alternating e.m.f., or voltage, such as, the ac generators and electronic oscillators, represented graphically by the symbol —(~)— The sinusoidal e.m.f.s, or voltages, are represented analytically as

$$v = V_0 \sin(\omega t)$$

where v is the instantaneous value, V_0 is the peak value, or amplitude, $\omega = 2\pi/T = 2\pi f$ is the angular frequency, T being the time period and f being the frequency, and ωt is the phase angle.

ADVANTAGES OF A.C. OVER D.C

(i) The generation of A.C. is cheaper than that of D.C.
(ii) Alternating voltage can be easily stepped up or stepped down by using a transformer.
(iii) A.C. can be easily converted into D.C. by rectifier.
(iv) It can be transmitted to a long distance without appreciable loss.

AVERAGE OR MEAN, VALUE OF ALTERNATING CURRENT

The average or mean, value of sinusoidal current $i = I_0 \sin(\omega t)$ over a complete cycle is

$$\begin{aligned}
I_{av} &= \frac{1}{T}\int_0^T i\,dt \\
&= \frac{1}{T}\int_0^T I_0 \sin(\omega t)dt \\
&= \frac{1}{T}\left[\frac{-I_0\cos(\omega t)}{w}\right]_0^T \\
&= \frac{1}{T}\left[\frac{-I_0\cos(2\pi)}{\omega} + \frac{I_0\cos(0)}{\omega}\right] \\
&= 0
\end{aligned}$$

It is zero because the integral represents the area between the curve and time axis over a complete cycle and this area is negative as much as it positive. This is the reason that if a sinusoidal current is sent through a moving-coil galvanometer, it reads zero. The non-zero average, or mean, value of sinusoidal current $i = I_0 \sin(\omega t)$ over a half-cycle is

$$\begin{aligned}
I_{av} &= \frac{2}{T}\int_0^{T/2} i\,dt \\
&= \frac{2}{T}\int_0^{T/2} I_0 \sin(\omega t)dt \\
&= \frac{2}{T}\left[\frac{-I_0\cos(\omega t)}{\omega}\right]_0^{T/2} \\
&= \frac{2}{T}\left[\frac{-I_0\cos\pi}{\omega} + \frac{I_0\cos(0)}{\omega}\right] = \frac{2I_0}{\pi} \approx 0.637 I_0
\end{aligned}$$

This average value is the height of rectangle, shown shaded in the figure, having it's area equal to the area under one loop of the sine curve.

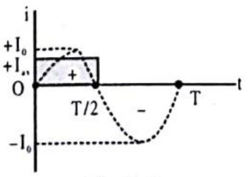

Fig. 7.41

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Similarly, the non-zero average, or mean, value of sinusoidal e.m.f., or voltage, $v = V_0 \sin(\omega t)$ over a half cycle is

$$V_{av} = \frac{2V_0}{\pi}$$

$$\approx 0.637V_0$$

ROOT-MEAN SQUARE (RMS) VALUE OF ALTERNATING CURRENT

Most of the ac meters are calibrated to record not the peak value of alternating current, or voltage, but the root-mean-square (rms) value, i.e., the square root of the average, or mean, of the square of current, or voltage. Because i^2 is always positive and the graph of i^2 against the time t lies above the t-axis, as shown, the average of i^2 is never zero, even when the average of i itself is zero. The average value of i^2, called the mean square current, over a complete cycle is

$$I^2_{rms} \equiv I^2 = \frac{1}{T}\int_0^T i^2 dt$$

$$= \frac{1}{T}\int_0^T I_0^2 \sin^2(\omega t)dt$$

$$= \frac{1}{T}\int_0^T \frac{I_0^2}{2}[1-\cos(2\omega t)]\, dt$$

$$= \frac{I_0^2}{2T}\left[t - \frac{\sin(2\omega t)}{2\omega}\right]_0^T \quad = \frac{I_0^2}{2T}\left[T - \frac{\sin(4\pi)}{2\omega} + \frac{\sin(0)}{2\omega}\right] = \frac{I_0^2}{2}$$

which is the height of rectangle, shown shaded in the figure.

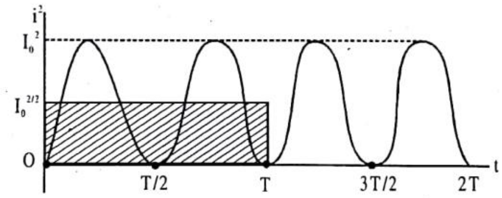

Fig. 7.42

It's square root gives the root-mean-square (rms) current, i.e.,

$$I_{rms} \equiv I = \frac{I_0}{\sqrt{2}} \approx 0.707I_0$$

Similarly, the root-mean-square (rms) value of a sinusoidal voltage is

$$V_{rms} \equiv V = \frac{V_0}{\sqrt{2}} \approx 0.707V_0$$

When a sinusoidal current $i = I_0 \sin(\omega t)$ flows through a resistance R, the average rate of heating during a complete cycle is given by

$$P = \frac{1}{T}\int_0^T i^2 R\, dt$$

$$= R\left[\frac{1}{T}\int_0^T i^2 dt\right] = R\,(I_{rms})^2$$

which also equals the rate of heating, when a dc of the value I_{rms} flows through the same resistance R. For this reason, I_{rms} is also called the effective value, or virtual value, or dc value, of ac.

The currents and voltages in the power distribution systems are always quoted in terms of their *rms* values. Thus, when we speak of our house-hold power supply as '220V ac', we mean to say that the *rms* voltage is 220V. Then, the peak voltage is

$$V_0 = \sqrt{2}V_{rms} = \sqrt{2} \times 220 \approx 311V$$

i.e., the voltage varies between +311V and −311V in a complete cycle. For the reason, an ac of 22V is more dangerous than a dc of 220V.

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ILLUSTRATION 7.6

If a domestic appliance draws 2.5 A from a 220-V, 60- Hz power supply, find

(a) the average current

(b) the average of the square of the current

(c) the current amplitude

(d) the supply voltage amplitude.

SOLUTION :

(a) The average of sinusoidal AC values over any whole number of cycles is zero.

(b) RMS value of current = $I_{rms} = 2.5$ A

$\therefore \quad (I^2)_{av} = (I_{rms})^2 = 6.25A^2$

(c) $I_{rms} = \dfrac{I_m}{\sqrt{2}}$

$\therefore$ Current amplitude $= \sqrt{2}I_{rms} = \sqrt{2}(2.5\,A) = 3.5$ A

(d) $V_{rms} = 220V = \dfrac{V_m}{\sqrt{2}}$

$\therefore$ Supply voltage amplitude

$V_m = \sqrt{2}(V_{rms}) = \sqrt{2}(220V) = 311$ V.

ILLUSTRATION 7.7

What is the ratio of mean value over half cycle to r.m.s. value of A.C.?

SOLUTION :

We know that $I_{rms} = I_0/\sqrt{2}$ and $I_m = 2I_0/\pi$

$\therefore \quad \dfrac{I_m}{I_{rms}} = \dfrac{2\sqrt{2}}{\pi}$

(i) Time period : The time taken by A.C. to go through one cycle of changes is called its period. It is given as $T = \dfrac{2\pi}{\omega}$

(ii) Phase : Phase is that property of wave motion which tells us the position of the particle at any instant as well as its direction of motion. It is measured either by the angle which the particle makes with the mean position or by fraction of time period.

(iii) Phase Angle : Angle associated with the wave motion (sine or cosine) is called phase angle.

(iv) Lead : Out of the current and e.m.f the one having greater phase angle will lead the other e.g. in equation

$i = i_0 \sin\left(\omega t + \dfrac{\pi}{2}\right)$ *and* $e = e_0 \sin \omega t$*, the current leads the e.m.f. by an angle* $\dfrac{\pi}{2}$.

(v) Lag : Out of current and e.m.f. the one having smaller phase angle will lag the other. In the above equations, the e.m.f lags the current by $\dfrac{\pi}{2}$.

RESISTANCE OFFERED BY VARIOUS ELEMENTS (RESISTOR, INDUCTOR, CAPACITOR) TO A.C.

Alternating current in a circuit may be controlled by resistance, inductance and capacitance, while the direct current is controlled only by resistance.

(i) **Impedance (Z) :** In alternating current circuit, the ratio of e.m.f. applied and consequent current produced is called the impedance and is denoted by Z, i.e., $\left[Z = \frac{E}{I} = \frac{E_0}{I_0} = \frac{E_{rms}}{I_{rms}}\right]$

Physically impedance of ac circuit is the hindrance offered by resistance alongwith either inductance or capacitance or both in the circuit to the flow of ac through it. Its unit is ohm.

(ii) **Reactance (X) :** The hindrance offered by inductance or capacitance or both to the flow of ac in an ac circuit is called reactance and is denoted by X. Thus when there is no ohmic resitance in the ciruict, the reactance is equal to impedance. The reactance due to inductance alone is called inductive reactance and is denoted by X_L, while the reactance due to capacitance alone is called the capacitive reactance and is denoted by X_C. Its unit is also ohm.

(iii) **Admittance.** The inverse of impedance is called the admittance and is denoted by Y, i.e., $Y = \frac{1}{Z}$

Its unit is ohm^{-1}.

IMPEDANCES AND PHASES OF AC CIRCUIT CONTAINING DIFFERENT ELEMENTS

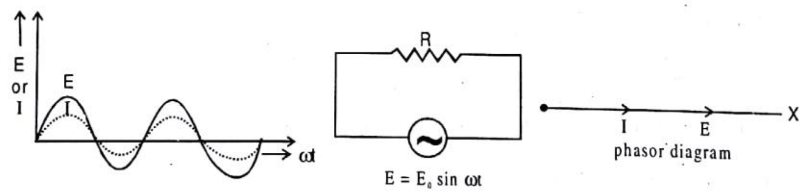
As already pointed out that in an ac circuit the current and applied e.m.f.'s are not necessarily in same phase. The applied e.m.f. (E) and current produced (I) may be expresed as

$E = E_0 \sin \omega t$ and $I = I_0 \sin (\omega t + \phi)$ with $I_0 = E_0/Z$

where E_0 and I_0 are peak values of alternating e.m.f. and current.

(i) **Circuit containing only resitance.** Consider a pure ohmic resistor (zero inductance) of resistance R connected to an alternating source of e.m.f. $E = E_0 \sin \omega t$. Then current I in the circuit is

$$I = \frac{E}{R} = \frac{E_0 \sin \omega t}{R} = I_0 \sin \omega t$$



(a) (b) (c)

Fig. 7.43

where $I_0 = E_0/R$

Comparing this with standard equation, we note that

Impedance of circuit, $Z = R$ and phase difference between current & e.m.f. = 0.

Hence we conclude that in a purely resistive ac circuit the current and voltage are in same phase and impedance of circuit is equal to the ohmic resistance.

(ii) **Circuit contianing only inductance.** Consider a pure inductor (zero ohmic resistance) of inductance L connected to an alternating source of e.m.f. $E = E_0 \sin \omega t$. Then current I in the circuit is

$$I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right) \qquad \text{where } I_0 = \frac{E_0}{\omega L}$$

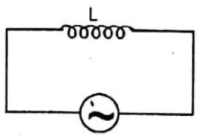


Fig. 7.44

Comparing this with standard equation, we know that

$Z = \omega L$ and $\phi = \pi/2$.

Hence we conclude that in a purely inductive circuit the current lags behind the applied voltage by an angle $\pi/2$ and the impedance to the circuit is ωL and this is called as inductive reactance.

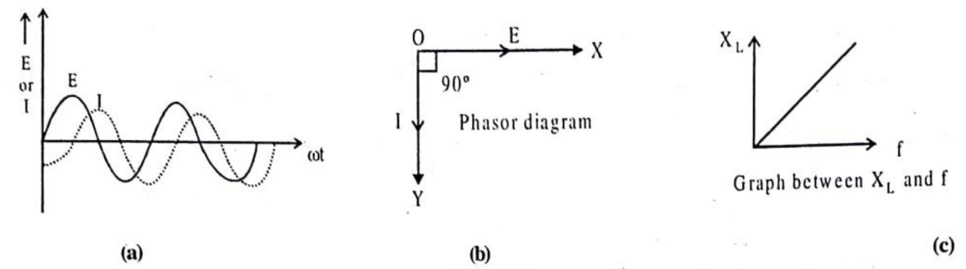


Fig. 7.45

(iii) Circuit Containing only Capacitance. Consider a capacitor of capacitance C connected to an alternating source of e.m.f., $E = E_0 \sin \omega t$.

Then the current through C is given by, $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

Comparing this with standard equation, we find that $X_C = 1/\omega C$ and $\phi = +\pi/2$

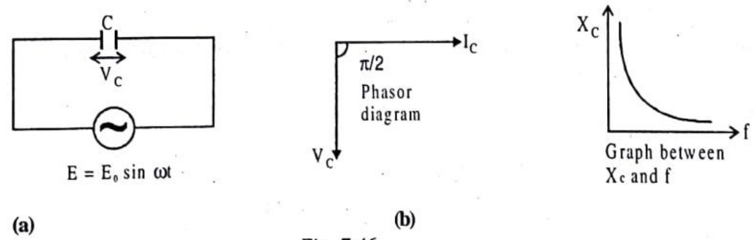


Fig. 7.46

Hence we conclude that in a purely capacitive circuit the current leads the applied e.m.f. by an angle $\pi/2$ and the impedance of the circuit is $1/\omega C$ and this is known as capacitive reactance $Z = X_C = \frac{1}{\omega C}$.

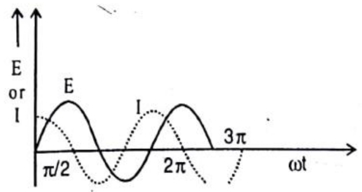


Fig. 7.47

CIRCUIT CONTAINING RESISTANCE, INDUCTANCE AND CAPACITANCE IN SERIES (SERIES LCR CIRCUIT)

Consider a circuit containing a resistance R, inductance L and capacitance C in series having an alternating e.m.f. $E = E_0 \sin \omega t$. Let, **I** be the current flowing in circuit. V_R, V_L and V_C are respective potential differences across resistance R, inductance L and capacitance C. The p.d. V_R is in phase with current **I**. The p.d. V_C lags behind the current by angle $\pi/2$. The p.d. V_L leads the current by angle $\pi/2$.

$\therefore$ Resultant applied e.m.f., $E = \sqrt{[V_R^2 + (V_C - V_L)^2]}$

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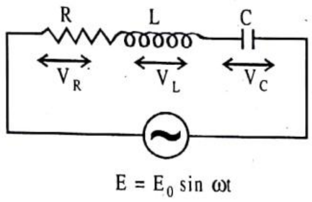

Fig. 7.48

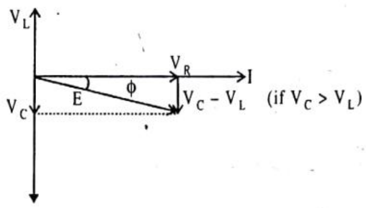

Fig. 7.49

i.e., $E = \sqrt{\{(RI)^2 + (IX_C - IX_L)^2\}}$

$\therefore$ Impedance, $Z = \dfrac{E}{I} = \sqrt{\{R^2 + (X_C - X_L)^2\}}$

The phase leads of current over applied e.m.f. is given by

$$\tan\phi = \frac{V_C - V_L}{V_R} = \frac{IX_C - IX_L}{RI} = \frac{X_C - X_L}{R}$$

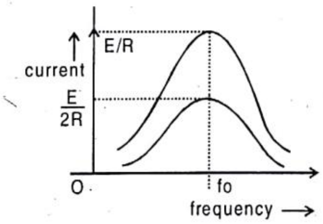

Fig. 7.50

i.e., $\phi = \tan^{-1}\left(\dfrac{X_C - X_L}{R}\right)$

It is concluded that

(a) If $X_C > X_L$, the value of ϕ is positive, i.e., current leads the applied e.m.f..

(b) If $X_C < X_L$, the value of ϕ is negative, i.e., current lags behind the applied e.m.f..

(c) If $X_C = X_L$, the value of ϕ is zero, i.e., current and e.m.f. are in same phase. This is called the case of **resonance** and resonant frequency for condition $X_C = X_L$, is given by :-

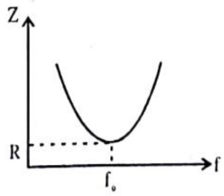

Fig. 7.51

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$\frac{1}{\omega C} = \omega L$ i.e., $\omega = \frac{1}{\sqrt{LC}}$

$\therefore\ f_o = \omega / 2\pi = \frac{1}{2\pi\sqrt{(LC)}}$.

Thus the resonant frequency depends on the product of L and C and is independent of R.

At resonance, impedance is minimum, $Z_{min} = R$ and current is maximum $I_{max} = \frac{E}{Z_{min}} = \frac{E}{R}$

It is interesting to note that before resonance the current leads the applied e.m.f., at resonance it is in phase, and after resonance it lags behind the e.m.f.. LCR series circuit is also called as acceptor circuit and parallel LCR circuit is called rejector circuit.

ILLUSTRATION – 7.8

Obtain the resonant frequency ω_r of a series LCR circuit with L = 2.0 H, C = 32 μF and R = 10Ω. What is the Q-value of this circuit?

SOLUTION :

Given,
$L = 2H, C = 32\ \mu F = 32 \times 10^{-6}$ F,
$R = 10\Omega, \omega_r = ?, Q = ?$
By relation,

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2\times 32\times 10^{-6}}} = \frac{10^3}{8} = 125 \text{ rad s}^{-1}.$$

Quality factor (Q-value) $\frac{\omega_r L}{R} = \frac{125\times 2}{10} = 25$

MISCELLANEOUS SOLVED EXAMPLES

1. Two coils are wound on the same iron rod so that the flux generated by one also passes through the other. The primary has 100 loops and secondary has 200 loops. When a current of 2 A flows through the primary the flux in it is 25 x 10^{-4} Wb. Determine value of M between the coils.

Sol. $|e_s| = N_s \frac{d\phi_s}{dt}$ and $|e_s| = M\frac{di_p}{dt}$;

$\therefore N_s \frac{d\phi_s}{dt} = M\frac{di_p}{dt}$ or $M = N_s \frac{d\phi_s}{di_p} = \frac{200(2.5\times10^{-4} - 0)}{(2-0)} = 2.5\times10^{-2} = 25$ mH

2. A small coil of radius r is placed at the centre of a large coil of radius R, where R >>r. The two coils are coplanar. The mutual induction between the coils is proportional to

(a) r/R **(b) r^2/R** **(c) r^2/R^2** **(d) r/R^2**

Sol. Let I be the current flow in the large coil.

$\therefore$ Mag. field at the centre of coil $B = \frac{\mu_0 I}{2R}$

Mag. flux linked with smaller coil

$$\phi = \pi r^2 B = \pi r^2 \left(\frac{\mu_0 I}{2R}\right)$$

But $\phi = MI$ $\quad \therefore M = \frac{\phi}{I} = \frac{\pi r^2 \mu_0}{2R}$ or $M \propto r^2/R$

3. Find the self inductance of a coil in which an e.m.f. of 10 V is induced when the current in the circuit changes uniformly from 1 A to 0.5 A in 0.2 sec.

Sol. Given : $e = 10\,V$ and $\frac{dI}{dt} = \frac{1-0.5}{0.2} = \frac{0.5}{0.2} = 2.5\ A/s$

Self inductance of coil $L = \frac{e}{dI/dt} = \frac{10}{2.5} = 4\ H$ $\quad \because e = L\frac{dI}{dt}$ (Considering magnitude only)

4. A conductor of length 10 cm is moved parallel to itself with a speed of 10 m/s at right angles to a uniform magnetic induction 10^{-4} Wb/m². What is the induced e.m.f. in it?

Sol. Given : $\ell = 10\,cm = 0.1\,m$, $v = 10\,m/s$

$B = 10^{-4}\ Wb/m^2$

e.m.f. induced in conductor $e = B\ell V = 10^{-4} \times 0.1 \times 10 = 10^{-4}\ V$

5. A metal rod of length 1 m is rotated about one of its ends in a plane right angles to a field of inductance 2.5×10^{-3} Wb/m². If it makes 1800 revolutions/min. Calculate induced e.m.f. between its ends.

Sol. Given : $\ell = 1m$, $B = 5 \times 10^{-3}\ Wb/m^2$ $\quad f = \frac{1800}{60} = 30$ rotations/sec

In one rotation, the moving rod of the metal traces a circle of radius $r = \ell$

$\therefore$ Area swept in one rotation $= \pi r^2$

$$\frac{d\phi}{dt} = \frac{d}{dt}(BA) = B.\frac{dA}{dt} = \frac{B\pi r^2}{T} = Bf\pi r^2 = (5 \times 10^{-3}) \times 3.14 \times 30 \times 1 = 0.471\ V$$

$\therefore$ e.m.f. induced in a metal rod $= 0.471$ V

6. A coil having 100 turns and area of 0.001 metre² is free to rotate about an axis. The coil is placed perpendicular to a magnetic field of 1.0 weber/metre². If the coil is rotate rapidly through an angle of 180°, how much charge will flow through the coil? The resistance of the coil is 10 ohm.

Sol. The flux linked with the coil when the plane of the coil is perpendicular to the magnetic field is

$\phi = nAB\cos\theta = nAB.$

the change in flux on rotating the coil by 180° is $d\phi = nAB - (-nAB) = 2nAB$

$\therefore$ induced charge $= \frac{d\phi}{R}$

$$= \frac{2nAB}{dt} = \frac{2 \times 100 \times 0.001 \times 1}{10}$$

$\therefore$ Induced charge = 0.01 coul.

7. Predict the direction of induced current in the situations described by the following fig. 7.51 (a) to 7.51 (e)

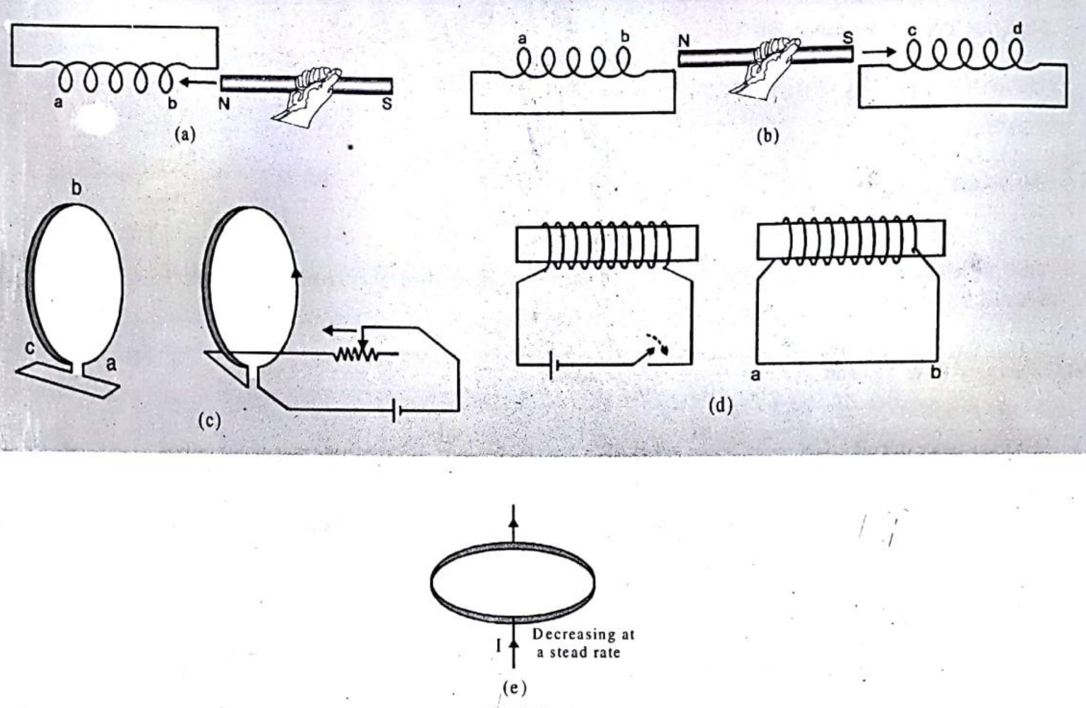

Fig.7.52

Sol. Applying Lenz's law

(1) along $a \to b$ (2) along $b \to a$, along $d \to c$ (3) along cba

(4) along $a \to b$ (5) No induced current since field lines lie in the plane of the loop.

8. A uniform magnetic field B exists in a cylindrical region, shown dotted in fig. The magnetic field increases at a constant rate dB/dt. Consider a circle of radius *r* coaxial with the cylindrical region. (a) Find the magnitude of the electric field E at a point on the circumference of the circle. (b) Consider a point P on the side of the square circumscribing the circle.

Show that the component of the induced electric field at P along ba is the same as the magnitude found in part (a).

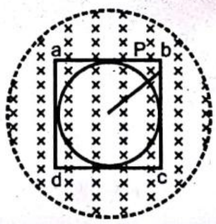

Fig. 7.53

Sol. Flux in the circle is, $\phi = B\pi r^2$

Emf induced is $= \dfrac{d\phi}{dt} = \dfrac{dB}{dt}\pi r^2$ ...(1)

Let the Electric field induced on the circumference is E. ($\because$ from symmetry it will be same at each point on circumference)

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1 EXERCISE

FIB Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. A generator converts mechanical energy into .... energy. It works on the basis of ....
2. In our houses we receive AC electric power of .... with a frequency of ....
3. The frequency for A.C. (alternating current) in USA is ....
4. The armature in a motor rotates within a(n) .... field.
5. To produce DC, the output of a generator must be fed through a (n) ....
6. In any generator, the current in the armature is of the .... type.
7. The phenomenon of production of back e.m.f. in a coil due to flow of varying current through it is called..............
8. The unit of self-inductance in SI system is ....
9. An e.m.f. is induced in a coil when .... linked with it changes.
10. In an AC generator, maximum number of lines of force pass through the coil when the angle between the plane of coil and lines of force is ....
11. A step down transformer steps up.......................and steps down ....
12. An AC generator can be converted into DC generator by replacing........... .
13. A transformer increases or decreases .... voltage.
14. Induced currents produced in a solid core placed in changing magnetic field is called an ....

T/F True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. An electric motor converts mechanical energy into electrical energy.
2. An electric generator works on the principle of electromagnetic induction.
3. In a DC electric motor a pair of split rings is used as commutator.
4. A transformer is an electrical device that works on the principle of self-induction.
5. Lenz's law is used to find out the magnitude of the induced e.m.f.
6. The Lenz's law is consistent with the law of conservation of energy.
7. Faraday observed that an e.m.f is produced across a conductor when the number of magnetic lines of force associated with the conductor changes.
8. The magnitude of e.m.f. induced in a circuit is inversely proportional to the rate of change of magnetic flux linked with circuit.
9. Induced current will appear in such a direction that it opposes the change that produced it.
10. Eddy current involves loss of energy in the form of heat.
11. S.I. unit of magnetic flux is weber. It is a vector quantity.
12. Energy stored in an inductor $= \frac{1}{2}LV^2$ it is magnetic energy.
13. The number of magnetic lines of force crossing is called magnetic flux linked with the surface.
14. When ever the magnetic flux linking a coil changes, then an e.m.f.. is induced in the magnet.
15. The induced e.m.f. depends only the turns of the coil
16. The magnitude of induced current can be increased by increasing the number of turns in coil.
17. The magnitude of induced current can be increased by decreasing the speed of rotation of coil.
18. The magnitude of induced current can be decreased by increasing the area of cross section of coil.

VSAQ Very Short Answer Questions :

DIRECTIONS : *Give answer in one word or one sentence.*

1. State Fleming's right hand rule.
2. Give the relation between V, N and I with respect to the primary and secondary coils of a transformer.
3. State Lenz's law.
4. What is the difference between an AC dynamo and a DC dynamo?
5. Give the principle of transformer? State the types of transformer
6. Can we produce electricity from magnetism ?
7. Does the A.C. generator have any slip ring ?
8. State two factors on which the magnitude and direction of induced e.m.f. depend.
9. How would you demonstrate that a momentary current can be obtained by the suitable use of a magnet and a coil of wire ? What is the source of energy associated with the current so obtained?
10. An alternating electric current has a frequency of 50 Hz. How many times does it change its direction in one second?

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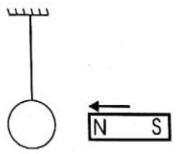
11. What will be the frequency of an alternating current if its direction changes after every 0.01 s?

12. Give the direction of induced current in the wire loop, when the magnet moves forward as shown in the figure.



13. State Faraday's law of electromagnetic induction.

14. Write S.I. unit of magnetic flux. Is it a scalar or a vector quantity?

15. Define the term self inductance. Give its unit.

16. If the number of turns in the solenoid is doubled, keeping other factors constant, how does the self inductance of the coil change?

17. Write an expression for the energy stored in an inductor of inductance L, when a steady current is passed through it. Is the energy electric or the magnetic?

18. If the rate of change of current is 2 A/s and induces an e.m.f. of 40 mV in the solenoid, what is the self inductance of the solenoid?

19. A pure resistance is connected to an ac source of 220 V, 50 Hz. What will be the phase difference between current and e.m.f. in the circuit

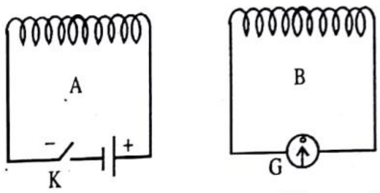
20. A pure inductance is connected to an a.c. source of 220 V, 50 Hz. What will be the phase difference and applied e.m.f. in the circuit ?

21. A pure capacitor is connected to an ac source of 220 V, 50 Hz. What will be the phase difference between current and applied e.m.f. in the circuit ?

SQA *Short Answer Questions :*

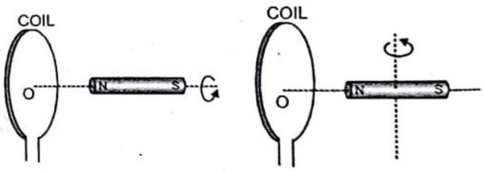
DIRECTIONS : *Give answer in two to three sentences.*

1. Explain different ways to induce current in a coil.
2. State the rule to determine the direction of a (i) magnetic field produced around a straight conductor-carrying current, (ii) force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it, and (iii) current induced in a coil due to its rotation in a magnetic field.
3. Explain the underlying principle of an electric generator. What is the function of brushes?
4. What is electromagnetic induction ? Describe one experiment to demonstrate the phenomenon of electromagnetic induction.
5. A flat rectangular coil is rotated between the pole pieces of a horse-shoe magnet. In which position of the coil with respect to the magnetic field, will the e.m.f. (i) be maximum (ii) be zero and (iii) change direction ?
6. Two coils A and B are placed as shown in figure. The coil A is connected to a battery and a key K while the coil B is connected to a centre zero galvanometer G. What will you observe in the galvanometer G when



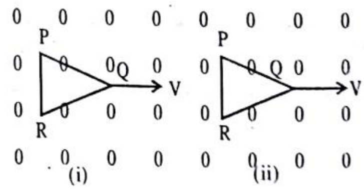
(i) the key K is closed. (ii) the key K is opened
(iii) with the key K closed, the coil A is moved rapidly towards the coil B.
(iv) with the key K closed, the coil B is moved rapidly towards the coil A.
(v) with the key K closed, the coils A and B are moved away from each other.

7. An induced e.m.f. has no direction of its own. Comment.
8. Two coils are being moved out of magnetic field one coil is moved rapidly and the other slowly. In which case is more work done and why?
9. A cylindrical bar magnet is kept along the axis of a circular coil and near it as shown in figure. Will there be any induced e.m.f. at the terminals of the coil, when the magnet is rotated (a) about its own axis and (b) about an axis perpendicular to the length of the magnet?

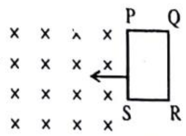


(a) (b)

10. A bar magnet falls from a height 'h' through a metal ring. Will its acceleration be equal to g? Give reason for your answer.
11. The given figure shows two positions of a loop PQR in a perpendicular uniform magnetic field. In which position of the coil is there an induced e.m.f.?



12.



The closed loop PQRS is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown. State the direction of the induced current in the loop.

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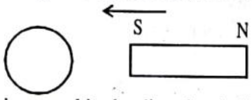
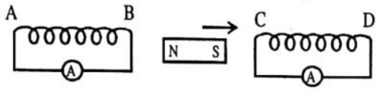
13. A vertical metallic pole falls down through the plane of the magnetic meridian. Will any e.m.f. be produced between its ends? Give reason for your answer.
14. The current through the wire PQ is increasing. In which direction does the induced current flow in the closed loop?

15. In which direction will the current be induced in the closed loop if the magnet is moved as shown in the figure.



16. A magnet is moved in the direction indicated by an arrow between two coils AB and CD as shown in the figure. Find the direction of current in each coil.



17. How does the self inductance of an air core coil change, when (i) the number of turns in the coil is decreased and (ii) an iron rod is introduced in the coil.
18. What is the difference between direct and alternating currents? Write one important advantage of using alternating current.

LAQ Long Answer Questions :

DIRECTIONS : *Give answer in four to five sentences.*

1. What is induced e.m.f? Write Faraday's law of electromagnetic induction. Explain it mathematically. A conducting rod of length 'l', with one end pivoted, is rotated with a uniform angular speed 'w' in a vertical plane, normal to a uniform magnetic field 'B'. Deduce an expression for the e.m.f. induced in this rod.
2. What do you mean by mutual inductance of two nearby coils? Find an expression for mutual inductance of a solenoid-coil system.
3. Explain with the help of a diagram, the principle and working of an a.c. generator. Write the expression for the e.m.f. generated in the coil in terms of speed of rotation. Can the current produced by an a.c. generator be measured with a moving coil galvanometer.
4. Derive an expression for the a.c. across a resistance R connected to an alternating source of e.m.f. $E = E_0 \sin wt$. Explain the variations of e.m.f. and current graphically and with a phasor diagram.
5. What is impedance? Give its SI unit. Using the phasor diagram or otherwise derive an expression for the impedance of an a.c. circuit containing L, C and R in series. Find the expression for resonant frequency.
6. Show diagramatically two different arrangements used for winding the primary and secondary coils in a transformer. Assuming the transformer to be an ideal one, write expression for the ratio of it's.
   (i) Output voltage to input voltage.
   (ii) Output current to input current.
   Mention the reasons for energy losses in an actual transformer.

2 EXERCISE

MCQ Multiple Choice Questions :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Two identical coaxial circular loops carry a current *i* each circulating in the same direction. If the loops approach each other, you will observe that
(a) the current in each increases,
(b) the current in each decreases,
(c) the current in each remains the same,
(d) the current in one increases whereas that in the other decreases

2. An induced e.m.f. is produced when a magnet is plunged into a coil. The strength of the induced e.m.f. is independent of
(a) the strength of the magnet
(b) number of turns of coil
(c) the resistivity of the wire of the coil
(d) speed with which the magnet is moved

3. Whenever the magnetic flux linked with a coil changes, an induced e.m.f. is produced in the circuit. The e.m.f. lasts
(a) for a short time
(b) for a long time
(c) for ever
(d) so long as the change in flux takes place

4. A magnet is moved towards a coil (i) quickly (ii) slowly, then the induced e.m.f. is

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(a) larger in case (i)
(b) smaller in case (i)
(c) equal in both the cases
(d) larger or smaller depending upon the radius of the coil

5. Lenz's law is a consequence of the law of conservation of
(a) charge (b) mass
(c) energy (d) momentum

6. The laws of electromagnetic induction have been used in the construction of a
(a) galvanometer (b) voltmeter
(c) electric motor (d) generator

7. A cylindrical bar magnet is kept along the axis of a circular coil. On rotating the magnet about its axis, the coil will have induced in it
(a) a current (b) no current
(c) only an e.m.f. (d) both an e.m.f. and a current

8. A moving conductor coil produces an induced e.m.f. This is in accordance with
(a) Lenz's law (b) Faraday's law
(c) Coulomb's law (d) Ampere's law

9. A coil of insulated wire is connected to a battery. If it is taken to galvanometer, its pointer is deflected, because
(a) induced current is produced
(b) the coil acts like a magnet
(c) the number of turns in the coil of the galvanometer are changed
(d) none of the above

10. A metal ring is held horizontally and bar magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet is
(a) equal to g
(b) less than g
(c) more than g
(d) depends on the diameter of ring and length of magnet

11. Whenever, current is changed in a coil, an induced e.m.f. is produced in the same coil. This property of the coil is due to
(a) mutual induction (b) self induction
(c) eddy currents (d) hysteresis

12. Two pure inductors, each of self inductance L are connected in parallel but are well separated from each other, then the total inductance is
(a) L (b) 2L
(c) L/2 (d) L/4

13. Two coils of self inductances L_1 and L_2 are placed so close together that effective flux in one coil is completely linked with the other. If M is the mutual inductance between them, then
(a) $M = L_1 L_2$ (b) $M = L_1 / L_2$
(c) $M = (L_1 L_2)^2$ (d) $M = \sqrt{(L_1 L_2)}$

14. An inductor may store energy in
(a) its electric field
(b) its coils
(c) its magnetic field
(d) both in electric and magnetic fields

15. If the number of turns per unit length of a coil of a solenoid is doubled, the self inductance of the solenoid will
(a) remain unchanged (b) be halved
(c) be doubled (d) become four times

16. If N is the number of turns in a coil, the value of self inductance varies as
(a) N^0 (b) N
(c) N^2 (d) N^{-2}

17. Two coils of inductances L_1 and L_2 are linked such that their mutual inducatance is M
(a) $M = L_1 + L_2$
(b) $M = \frac{1}{2}(L_1 + L_2)$
(c) The maximum value of M is $(L_1 + L_2)$
(d) The minimum value of M is $\sqrt{L_1 L_2}$

18. The SI unit of inductance, henry, can be written as
(a) weber/ampere (b) volt second/ampere
(c) joule/ampere^2 (d) all of these

19. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon
(a) relative position and orientation of the two coils.
(b) the materials of the wires of the coils.
(c) the currents in the two coils
(d) the rates at which currents are changing in the two coils

20. A capacitor acts as an infinite resistance for
(a) DC (b) AC
(c) DC as well as AC (d) neither AC nor DC

21. An inductor, a resistor and a capacitor are joined in series with an AC source. As the frequency of the source is slightly increased from a very low value, the reactance
(a) of the inductor increases
(b) of the reasistor increases
(c) of the capacitor increases
(d) of the circuit increases

22. An A.C. source is connected to a resistive circuit. What is true of the following
(a) current leads ahead of voltage in phase
(b) current lags behind voltage in phase
(c) current and voltage are in same phase
(d) any of the above may be true depending upon the value of resistance.

23. The capacitive reactance in an A.C. circuit is
(a) effective resistance due to capacity
(b) effective wattage
(c) effective voltage
(d) none of the above

24. The power factor in a circuit connected to an A.C. The value of power factor is
(a) unity when the circuit contians an ideal inductance only
(b) unity when the circuit contians an ideal resistance only
(c) zero when the circuit contains an ideal resistance only
(d) unity when the circuit contains an ideal capacitance only

25. Current in a circuit is wattless if
(a) inductance in the circuit is zero
(b) resistance in the circuit is zero
(c) current is alternating
(d) resistance and inductance both are zero

26. Power factor is one for
(a) pure inductor
(b) pure capacitor
(c) pure resistor
(d) either an inductor or a capacitor.

27. Of the following about capacitive reactance which is correct
(a) the reactance of the capacitor is directly proportional to its ability to store charge
(b) capacitive reactance is inversely proportional to the frequency of the current
(c) capacitive reactance is mesured in farad
(d) the reactance of a capacitor in an A.C. circuit is similar to the resistance of a capacitor in a D.C. circuit

28. With increase in frequency of an A.C. supply, the inductive reactance
(a) decrease
(b) increases directly proportional to frequency
(c) increases as square of frequency
(d) decreases inversely with frequency

29. With increase in frequency of an A.C. supply, the impedance of an L-C-R series circuit
(a) remains constant
(b) increases
(c) decreases
(d) decreases at first, becomes minimum and then increases.

30. For long distance transmission, the ac is stepped up because of high voltage, the transmission is
(a) faster (b) economical
(c) undamped (d) less dangerous

31. The transformer voltage induced in the secondary coil of a transformer is mainly due to
(a) a varying electric field
(b) a varying magnetic field
(c) the vibrations of the primary coil
(d) the iron core of the transformer

32. Eddy currents in the core of transformer can't be developed
(a) by increasing the number of turns in secondary coil
(b) by taking laminated transformer
(c) by making step down transformer
(d) by using a weak a.c. at high potential

33. The frequency of A.C. mains in India is
(a) 30 c/s (b) 50 c/s
(c) 60 c/s (d) 120 c/s

34. Hot wire ammeters are used for measuring
(a) A.C. only (b) D.C. only
(c) both A.C. and D.C. (d) none of these

35. Alternating current cannot be measured by D.C. ammeter because
(a) A.C. cannot pass through D.C. ammeter
(b) average value of current for complete cycle is zero
(c) A.C. is virtual
(d) A.C. changes its direction

36. Alternating current is converted to direct current by
(a) rectifier (b) dynamo
(c) transformer (d) motor

37. A transformer is employed to
(a) convert A.C. into D.C.
(b) convert D.C. into A.C.
(c) obtain a suitable A.C. voltage
(d) obtain a suitable D.C. voltage

38. To convert mechanical energy into electrical energy, one can use
(a) DC dynamo (b) AC dynamo
(c) motor (d) (a) & (b)

39. The AC voltage across a resistance can be meausred using
(a) a potentiometer
(b) a hot-wire voltmeter
(c) a moving-coil galvanometer
(d) a moving-magnet galvanometer

40. A choke is preferred to a resistance for limiting current in A.C. circuit because
(a) choke is cheap
(b) there is no wastage of energy
(c) current becomes wattless
(d) current strength increases

41. A choke coil has
(a) high inductance and high resistance
(b) low inductance and low resistance
(c) high inductance and low resistance
(d) low inductance and high resistance

42. Transformers are used
(a) in DC circuit only
(b) in AC circuits only
(c) in both DC and AC circuits
(d) neither in DC nor in AC circuits

43. A rectangular coil of copper wires is rotated in a magnetic field. The direction of the induced current changes once in each
(a) two revolutions (b) one revolution
(c) half revolution (d) one-fourth revolution

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44. The phenomenon of electromagnetic induction is –
(a) the process of charging a body.
(b) the process of generating magnetic field due to a current passing through a coil.
(c) producing induced current in a coil due to relative motion between a magnet and the coil.
(d) the process of rotating a coil of an electric motor.

45. The device used for producing electric current is called a
(a) generator (b) galvanometer
(c) ammeter (d) motor

46. The essential difference between an AC generator and a DC generator is that
(a) AC generator has an electromagnet while a DC generator has permanent magnet.
(b) DC generator will generate a higher voltage.
(c) AC generator will generate a higher voltage.
(d) AC generator has slip rings while the DC generator has a commutator.

47. At the time of short circuit, the current in the circuit
(a) reduces substantially (b) does not change.
(c) increases heavily (d) vary continuously

48. The direction of induced current is obtained by
(a) Fleming's left hand rule
(b) Right hand thumb rule
(c) Biot and Savart rule
(d) Fleming's right hand rule

49. In an electric motor, conversion takes place of
(a) Chemical energy into electrical energy
(b) Electrical energy into mechanical energy
(c) Electrical energy into light
(d) Electrical energy into chemical energy

50. The current in a generator armature is AC because
(a) the magnetic field reverses at intervals
(b) the current in the field coils is AC
(c) the rotation of the armature causes the field through it to reverse
(d) the commutator feeds current into it in opposite directions every half cycle

51. The current in the armature of a motor is reversed every half cycle due to the action of a(n)
(a) armature (b) field coil
(c) brush (d) commutator.

52. For dynamo which one of the following statements is correct
(a) It converts the electrical energy into light energy
(b) It converts the kinetic energy into heat energy
(c) It converts the mechanical energy into electrical energy
(d) It converts the electrical energy into mechanical energy

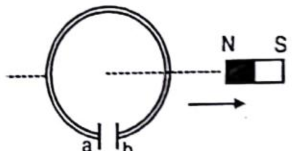
53. In an electric motor, the energy transformation is
(a) from electrical to chemical
(b) from chemical to light
(c) from mechanical to electrical
(d) from electrical to mechanical

54. The direction of induced current is obtained by
(a) Fleming's left hand rule
(b) Maxwell's cork-screw rule
(c) Ampere's rule
(d) Fleming's right hand rule

55. Which of the following has its working based on electromagnetic induction –
(a) Ammeter (b) Voltmeter
(c) Transformer (d) Galvanometer

56. A cylindrical bar magnet is kept along the axis of a circular coil. If the magnet is rotated about its axis, then –
(a) a current will be induced in the coil
(b) no current will be induced in the coil
(c) only emf will be induced in the coil
(d) an emf and current both will be induced in the coil

57. Consider the arrangement shown in figure in which the north pole of a magnet is moved away from a thick conducting loop containing capacitor. Then excess positive charge will arrive on



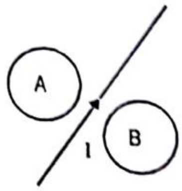
(a) plate a
(b) plate b
(c) on both plates a and b
(d) on neither a nor b plates

58. The north pole of a magnet is brought near a coil. The induced current in the coil as seen by an observer on the side of magnet will be
(a) in the clockwise direction
(b) in the anticlockwise direction
(c) initially in the clockwise and then anticlockwise direction
(d) initially in the anticlockwise and then clockwise direction

59. Lenz's law is consistent with law of conservation of -
(a) current (b) emf
(c) energy (d) all of the above

60. When a magnet is being moved towards a coil, the induced emf does not depend upon
(a) the number of turns of the coil
(b) the motion of the magnet
(c) the magnetic moment of the magnet
(d) the resistance of the coil

61. Consider the situation shown in figure. If the current I in the long straight wire XY is increased at a steady rate then the induced emf's in loops A and B will be -



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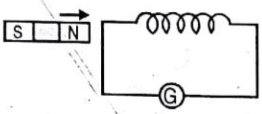
(a) clockwise in A, anticlockwise in B
(b) anticlockwise in A, clockwise in B
(c) clockwise in both A and B
(d) anticlockwise in both A and B

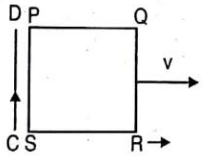
62. Direction of induced e.m.f. is determined by -
(a) Fleming's left hand rule
(b) Fleming's right hand rule
(c) Maxwell's rule
(d) Ampere's rule of swimming

63. A magnet is brought towards a fixed coil rapidly. Due to this induced emf, current and charge are E, I and Q respectively. If the speed of the magnet is doubled, then wrong statement is -



(a) E increases
(b) I increases
(c) Q remains unchanged
(d) Q increases

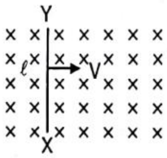
64. A square loop PQRS is carried away from a current carrying long straight conducting wire CD. The direction of induced current in the loop will be



(a) anticlockwise
(b) clockwise
(c) sometimes clockwise some times anticlockwise
(d) current will not be induced

65. A thin sheet of conductor, when allowed to oscillate in a magnetic field normal to the sheet, then the motion is -
(a) damped due to air friction
(b) damped due to eddy currents
(c) accelerated due to eddy currents
(d) not effected by induced currents

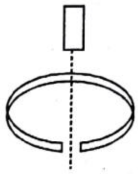
66. A small conducting rod of length ℓ, moves with a uniform velocity v in a uniform magnetic field B as shown in figure.



(a) Then the end X of the rod becomes positively charged
(b) the end Y of the rod becomes positively charged
(c) the entire rod is unerringly charged
(d) the rod becomes hot due to joule heating

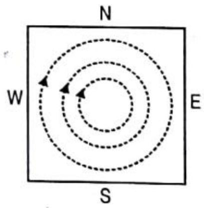
67. The armature current in D.C. motor is maximum when the motor has -
(a) picked up maximum speed
(b) just started
(c) intermediate speed
(d) just been switched off

68. A copper ring having a cut such as not to form a complete loop is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring. Then acceleration of the falling magnet is -(neglect air friction)



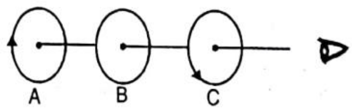
(a) g (b) less than g
(c) more than g (d) 0

69. A metal sheet is placed in a variable magnetic field which is increasing from zero to maximum. Induced current flows in the directions as shown in figure. The direction of magnetic field will be -



(a) normal to the paper, inwards
(b) normal to the paper, outwards
(c) from east to west
(d) from north to south

70. Three closed similar coils A, B and C are placed such that their planes are parallel. In the coil A and C, current of same magnitude flows as shown in the figure. Coils B & C are static while coil A is moved with a uniform speed towards B, then -



(a) clockwise current will be induced in coil B
(b) anti-clockwise current will be induced in coil B
(c) no current will flow in coil B
(d) current induced in coil B will be equal to A and C, but in opposite direction, hence net current in B will be zero

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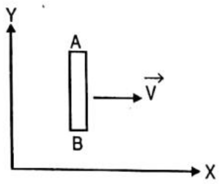
71. A conductor rod AB moves parallel to X-axis in a uniform magnetic field, pointing in the positive Z-direction. The end A of the rod gets-



(a) positively charged
(b) negatively charged
(c) neutral
(d) first positively charged and then negatively charged

MTOC More than One Correct :

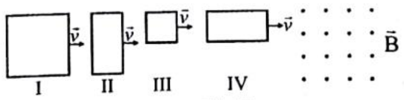
DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. The reactance of a circuit is zero. It is possible that the circuit contains
(a) an inductor and a capacitor
(b) an inductor but no capacitor
(c) a capacitor but no inductor
(d) neither an inductor nor a capacitor

2. In an AC series circuit, the instantaneous current is zero when the instantaneous voltage is maximum.Connected to the source may be a
(a) pure inductor
(b) pure capacitor
(c) pure resistor
(d) combination of an inductor and a capacitor

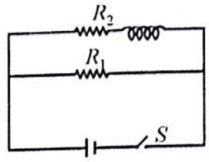
3. An inductor-coil having some resistance is connected to an AC source. Which of the following quantities have zero average value over a cycle?
(a) current
(b) induced e.m.f. in the inductor
(c) joule heat
(d) magnetic energy stored in the inductor

4. The figure shows four wire loops, with edge lengths of either ℓ or 2ℓ. All four loops will move through a region of uniform magnetic field $\vec{B}$ at the same constant velocity. In which loop the emf induced is maximum :



(a) I (b) II
(c) III (d) IV

5. Figure shows a circuit with two resistors and an ideal inductor.



(a) The current in R_1 is zero just after closing the switch S.
(b) The current in R_1 is maximum just after closing the switch S.
(c) The current in R_2 is zero just after closing of the switch S.
(d) The currents in the resistors are maximum of their values a long time after closing the switch S.

6. L, C and R represent inductance, capacitance and resistance respectively. Which of the following have dimensions of frequency ?

(a) $\frac{L}{C}$ (b) $\frac{1}{\sqrt{LC}}$

(d) $\frac{R}{L}$ (d) $\frac{1}{RC}$

7. A conducting loop is placed in a uniform magnetic field with its plane perpendicular to the field. An emf is induced in the loop if
(a) it is translated
(b) it is rotated about its axis
(c) it is rotated about its axis.
(d) it is expended

8. If the inductance L in an oscillating LC circuit having a given maximum charge Q is increased, then
(a) the current magnitude increases
(b) the maximum magnetic energy increases
(c) the maximum magnetic energy decreases
(d) current magnitude and maximum magnetic energy remain constant.

9. An alternating e.m.f. of frequency $f\left(=\frac{1}{2\pi\sqrt{LC}}\right)$ is applied to a series LCR circuit. For this frequency of the applied e.m.f.
(a) The circuit is at resonance and its impedance is made up only of a reactive part
(b) The current in the circuit is in phase with the applied e.m.f. and the voltage across R equals this applied emf
(c) The sum of the p.d.'s across the inductance and capacitance equals the applied e.m.f. which is 180° ahead of phase of the current in the circuit
(d) The quality factor of the circuit is $\omega L / R$ or $1 / \omega CR$ and this is a measure of the voltage magnification (produced by the circuit at resonance) as well as the sharpness of resonance of the circuit

10. The magnetic flux (ϕ) linked with a coil depend son time t as $\phi = at^n$, where a is a constant. The induced e.m.f. in the coil is *e*.
(a) If $0 < n < 1, e = 0$
(b) If $0 < n < 1, e \neq 0$ and $|e|$ decreases with time
(c) If $n = 1$, e is constant
(d) If $n > 1$, $|e|$ increases with time

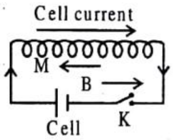
11. In which of the following cases does the electromagnetic induction occur –
(a) a current is started in a wire held near a loop of wire
(b) the current is stopped in a wire held near a loop of wire
(c) a magnet is moved through a loop of wire
(d) a loop of wire is held near a magnet

FIP Fill in the Passage :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

increases,	*oppose,*	*self induction,*	*magnetic flux*
induced,	*opposite,*	*gradually*	

I ....1............ is a property of a coil due to which the coil opposes any chane in the strength of current flowing through it by inducting an e.m.f. in itself.



In the adjacent circuit shown, on closing the key (K) the current through the coil increases from zero to a certain maximum value in a certain time (M). As the current increases ....2............ , the magnetic field linked with the coil also ....3............ . Therefore, the induced current in the coil according to Lenz's law will ....4............ the growth of current in the coil, flowing in the direction opposite to that of the cell current.

When the key is released, the current decreases from maximum to zero value in a certain time. Therefore, ...5............ linked with the coil also decreases and an ....6............ current is produced in the coil which will oppose the decay of current flowing in a direction ....7............ to it.

II *primary, secondary, alternating, transfomation transformer.*

Transformer is a device used to change an ....1............ voltage from one to another of greater or smaller value. It is based on the principle of mutual induction.

A transformer consists of two sets of coils, insulated from each other. One of the coils called the primary coil has N_P turns. The other coil is called the secondary coil, it has N_S turns. The ....2............ coil is the input coil and the ....3............ coil is the output coil of the transformer.

If it is assumed that there is no energy loses, the input power is equal to output power.

$i_P V_P = i_S V_S$, $i_P \rightarrow$ Primary current, $i_S \rightarrow$ Secondary current

$\frac{i_P}{i_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$ $V_P \rightarrow$ Primary voltage, $V_S \rightarrow$ Secondary voltage where $\frac{N_S}{N_P} = k$ is known as ....4............ ratio.

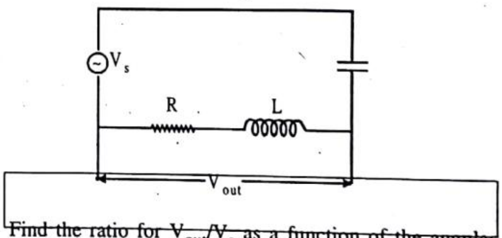
A ....5............ affects the voltage and current according to relation, $V_S = \left(\frac{N_S}{N_P}\right)V_p$ and $I_P = \left(\frac{N_P}{N_S}\right)I_P$.

PBQ Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

Passsage I

One application of LRC series circuit is to high pass or low pass filters, which filter out either the low or high frequency components of a signal. A high pass filter is shown in figure, where the output voltage is taken across the LR combination, where LR combination represents an inductance coil that also has resistance due to large length of the wire in the coil.



1. Find the ratio for V_{out}/V_s as a function of the angular frequency ω of the source :

(a) $\sqrt{\frac{R^2 + \omega L^2}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$ (b) $\sqrt{\frac{R^2 + (\omega L)^2}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$

(c) $\sqrt{\frac{R^2 + \omega^2 L}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$ (d) 1

2. Which of the following statements is correct when ω is small, in the case of V_{out}/V_s?

(a) ωRC (b) $\frac{\omega R}{L}$

(c) ωRL (d) $\frac{\omega R}{C}$

3. Which statement is correct in the limit of large frequency is reached? (For V_{out}/V_s?)

(a) 1 (b) ωRC

(c) ωRL (d) $\frac{\omega R}{L}$

Passage II

Modern Trains are based on Maglev technology in which trains are magnetically leviated, which runs its EDS Maglev System. These are coils on both sides of wheels. Due to motion of train current induces in the coil of track which levitate it. This is in accordance with Lenz's law. If trains lower down, then due to Lenz's law a repulsive force increases due to which train gets uplifted and if it goes much high then there is a net downward force due to gravity. The advance of Maglev train is that there is no friction ebtween the trains and the track, thereby reducing power consumption and enabling the train to attain very high speeds. Disadvantage of Maglev train is that as it slows down the electromagnetic force decreases and it become difficult to keep it leviated and as it moves forwards, according to Lenz's law there is an electromagnetic drop force.

1. What is the advantage of this system?
   (a) No friction, hence no power consumption
   (b) No electric power is used
   (c) Gravitation force is zero
   (d) Electrostatic force draws the train

2. What is the disadvantage of this system?
   (a) Train experiences an upward force according to Lenz's law
   (b) Friction force creates a drag on the train
   (c) Retardation
   (d) By Lenz's law, train experiences a drag

3. Which force causes the train to elevate up?
   (a) Electrostatic force
   (b) Time varying electric field
   (c) Magnetic force
   (d) Induced electric field

Passsage III

A fresh man physics lab is designed to study the transfer of electrical energy from one circuit to another by means of a magnetic field using simple transformers. Each transformer has two coils of wire electrically insulated from each other but wound around a common core of ferromagnetic material. The two wires are close together but do not touch each other. The primary coil is connected to a resistor such as a light bulb. The AC source produces an oscilating voltage and current int he primary coil that produces an oscillating magnetic field in the core material. This in turn induces an oscilating voltage and AC current in the secondary coil. Students collected the following data comparing the number of turns per coil (N), the voltage (V) and the current (I) in the coils of three transformeers.

	Primary Coil			Secondary Coil		
	N_1	V_1	I_1	N_2	V_2	I_2
Transformer 1	100	10V	10A	200	20V	5A
Transformer 2	100	10V	10A	50	5V	20A
Transformer 3	200	10V	10A	100	5V	20A

1. The primary coil of a transformer has 100 turns and is connected to a 120V AC source. How many turns are in the secondary coil if there is a 2400V across it?
   (a) 5 (b) 50
   (c) 200 (d) 2000

2. A transformer with 40 turns in its primary coil is connected to a 120 V AC source. If 20 watts of power is supplied to the primary coil, how much power is developed int eh secondary coil?
   (a) 10 W (b) 20 W
   (c) 80 W (d) 160 W

3. Which of the following is a correct expression for R, the resistance of the load connected to the secondary coil?
   (a) $\left(\frac{V_1}{I_1}\right)\left(\frac{N_2}{N_1}\right)$ (b) $\left(\frac{V_1}{I_1}\right)\left(\frac{N_2}{N_1}\right)^2$
   (c) $\left(\frac{V_1}{I_1}\right)\left(\frac{N_1}{N_2}\right)$ (d) $\left(\frac{V_1}{I_1}\right)\left(\frac{N_1}{N_2}\right)^2$

4. The primary coil of a given transformer has $\frac{1}{3}$ as many turns as in its secondary coil. What primary current is required to provide a secondary current of 3.0 mA?
   (a) 1.0 mA (b) 6.0 mA
   (c) 9.0 mA (d) 12.0 mA

5. A 12 V battery is used to supply 2.0 mA of current to the 300 turns in the primary coil of a given transformer. What is the current in the secondary coil if $N_2 = 150$ turns?
   (a) 0A (b) 1.0 mA
   (c) 2.0 mA (d) 4.0 A

A&R Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) **Assertion** is false, **Reason** is true

(b) **Assertion** is true, **Reason** is true; **Reason** is a correct explanation for **Assertion**

(c) **Assertion** is true, **Reason** is true; **Reason** is not a correct explanation for **Assertion**

(d) **Assertion** is true, **Reason** is false

1. **Assertion :** An induced e.m.f. appears in any coil in which the current is changing.

   Reason : Self induction phenomenon obeys Faraday's law of induction.

2. **Assertion :** Lenz's law violates the principle of conservation of energy.

   Reason : Induced e.m.f. always opposes the change in magnetic flux responsible for its production.

3. **Assertion :** When number of turns in a coil is doubled, coefficient of self-inductance of the coil becomes 4 times.

   Reason : This is because $L \propto N^2$.

4. **Assertion :** An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.

   Reason : Above statement is in accordance with conservation of energy.

5. **Assertion :** The coil in the resistance boxes are made by doubling the wire.

   Reason : Thick wire is required in resistance box.

6. **Assertion :** When variable frequency a.c. source is connected to a capacitor, displacement current increases with increase in frequency.

   Reason : As frequency increases conduction current also increases.

7. **Assertion :** A capacitor blocks direct current in the steady state.

   Reason : The capacitive reactance of the capacitor is inversely proportional to frequency f of the source of e.m.f..

8. **Assertion :** In the purely resistive element of a series LCR, AC circuit the maximum value of rms current increases with increase in the angular frequency of the applied e.m.f.

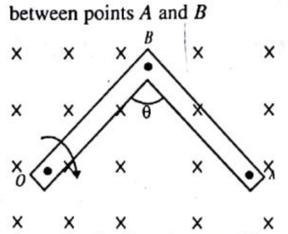
   Reason : $I_{max} = \frac{\varepsilon_{max}}{z}$, $z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$,

   where I_{max} is the peak current in a cycle.

MMQ Multiple Matching Questions :

DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1. Column I gives some incomplete statements. Column II gives some completing statements. Match them correctly.

Column I	Column II
(A) A rod rotates in a uniform transverse magnetic field as shown, about hinge at *O*. Potential difference between points *A* and *B* 	(p) may be zero
(B) A conducting loop is moved in a region of transverse constant magnetic field (infinite region), downward the plane of paper, as shown. Value of induced current *i*	(q) must be zero

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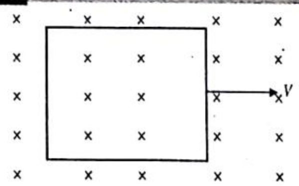
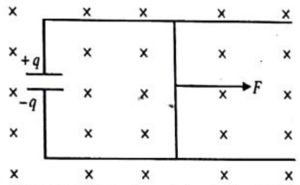


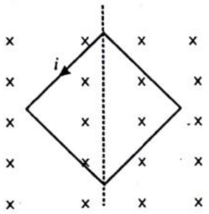
(C) If a constant force F is acting on the wire, rate of change of charge q stored by the capacitor, $\frac{dq}{dt}$ ......

(r) may be negative



(D) A square loop is rotated about diagonal in a region of uniform magnetic field as shown.
Value of i at an instant ....

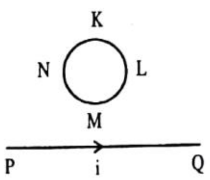
(s) may be positive
(t) must be positive



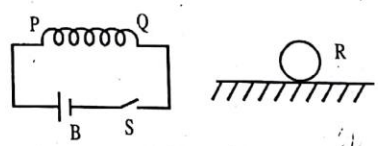
HOTS Subjective Questions :

DIRECTIONS : *Answer the following questions.*

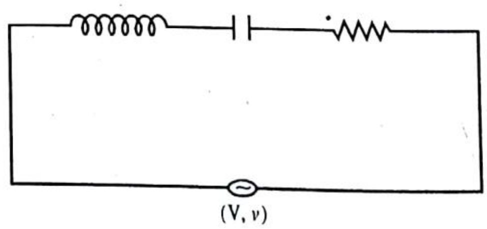
1. If the self inductance of an iron core inductor increases from 0.01 mH to 10 mH on introducing the iron core into it, what is the relative permeability of the core material used?
2. What is the magnitude of the induced current in the circular loop KLMN, of radius 'r' if the straight wire PQ carries a steady current of magnitude 'i' A?



3. The following figure shows a horizontal solenoid 'PQ' connected to a battery 'B' and switch 'S'. A copper ring 'R' is placed on a frictionless track, the axis of the ring being along the axis of the solenoid. What would happen to the ring as the switch 'S' is closed?



4. Name the main component which changes a.c generator in to d.c. generator.
5. Write the expression for the efficiency of d.c. motor?
6. The series LCR circuit shown in the figure is in resonance. Calculate the voltage across the inductor in terms of the source voltage and frequency.



7. In a transformer $\frac{V_S}{V_P} = \frac{N_S}{N_P}$. What are the assumption made in obtaining the relation?

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8. A bulb and capacitor connected in series to a source of ac. What will happen on increasing the frequency of the ac?

9. Can a LCR circuit exhibit the phenomenon of electrical oscillation?

10. A bulb and an inductor are connected in series to a source of alternating current. What will happen on increasing the frequency of a.c. source?

11. What will be the effect on inductive reactance X_L and capacitive reactance X_C, if frequency of a.c. source is increased?

12. What is the phase difference between the voltage across the inductance and capacitor in an a.c circuit?

13. On what principle does a metal detector work?

14. What is the value of power factor at resonance in LCR circuit?

15. The divisions marked on the scale of an a.c. ammeter are not equally spaced. Why?

16. How are eddy currents produced? Give two applications of eddy current.

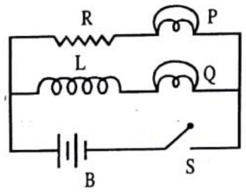
17. How does the mutual inductance of a pair of coils change when:

(i) the distance between the coils is increased?

(ii) the number of turns in each coil is dicreased?

Justify your answer in each case.

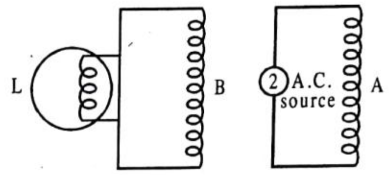
18. The given figure shows an inductor L and resistor R connected in parallel to a battery B through a switch S. The resistance of R is same as that of the coil that makes L. Two identical bulbs, P and Q are put in each arm of the circuit as shown in the figure. When S is closed, which of the two bulbs will light up earlier? Justify your answer.



19. In the diagram given, a coil B is connected to low voltage bulb L and placed parallel to another coil 'A' as shown. Explain the following observations.

(i) Bulb lights and

(ii) Bulb gets dimmer if the coil 'B' is moved upwards.



20. A cyclindrical bar magnet is kept along the axis of a circular coil and near it as shown in the diagram will near be any induced e.m.f at the terminals of the coil, when the magnet is rotated (a) about its own axis, and (b) about an axis perpendicular to the length of the magnet?

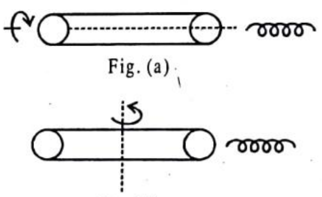
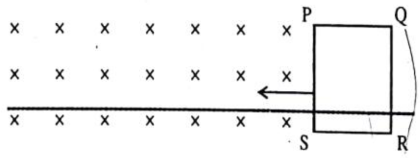


Fig. (a)

Fig. (b)

21. The closed loop PQRS is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown in the following figure. State the direction in which the induced current flows in the loop.



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SOLUTIONS

Brief Explanations of Selected Questions

Exercise 1

FILL IN THE BLANKS :

1. electrical, electromagnetic induction.
2. 220 V, 50 Hz.
3. 60 Hz
4. magnetic
5. commutator
6. A.C
7. self-induction
8. henry
9. the magnetic flux
10. 90°
11. current, voltage
12. slip rings with split rings
13. A.C
14. eddy current

TRUE / FALSE

1. False	2. True	3. True	4. False
5. False	6. True	7. True	8. False
9. True	10. True	11. False	12. False
13. True	14. False	15. False	16. True
17. False	18. False		

VERY SHORT ANSWER QUESTIONS :

1. M, B, I are represented by thumb, forefinger and middle finger of the right hand.

2. $$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

3. The direction of the induced current is such that it opposes the very cause that produces it.

4. Produces AC and DC currents respectively.

5. Electromagnetic induction.
   (i) step-up
   (ii) step-down transformers.

6. Yes.

7. The A.C. generator has two slip rings.

10. Frequency of an alternating current is 50 Hz. It changes the direction after every sec. i.e. the direction of current change 100 times per second.

11. 50 Hz.

12. Anticlockwise from the side of the magnet.

13. According to Faraday's law, the rate at which the magnetic flux changes gives induced e.m.f. The induced e.m.f. always opposes the change that brings it.

14. S.I. unit of magnetic flux is weber. It is a scalar quantity.

15. The self inductance of a coil is defined as the magnetic flux linked with the coil when unit current flows through it. S.I. unit is henry.

16. Self inductance L μ N^2, so when the number of turns is doubled, self inductance will become 4 times.

17. Energy stored in an inductor $= \frac{1}{2}LI^2$. It is magnetic energy.

18. Induced e.m.f. $= e = -L\frac{di}{dt}$

$$\therefore \quad L = \left|\frac{e}{di/dt}\right| = \frac{40\times10^{-3}}{2} = 20\times10^{-3}\,H = 20\,mH.$$

19. In a pure resistive circuit the phase difference between current and the voltage is zero.

20. In a pure inductor, the current lags behind the applied e.m.f. by $\pi/2$.

21. In a pure capacitive circuit, the current leads the voltage by $\pi/2$.

SHORT ANSWER QUESTIONS :

1. (i) A current is induced in a coil when a magnet is moved relative to the fixed coil.
   (ii) A current is also induced in a coil when it is moved relative to a fixed magnet.
   (iii) Not any current is induced in a coil when the coil and magnet both are stationary relative to one another.
   (iv) When the direction of motion of magnet or coil is reversed, the direction of current induced in the coil also gets reversed.

2. (i) The direction of magnetic field produced around a current-carrying conductor is given by right hand thumb rule. If the conductor carrying current is held in the right hand in such a way that the thumb points in the direction of current, then direction of curl of fingers gives the direction of the magnetic field.
   (ii) The direction of force experienced by a straight conductor carrying-current placed in a magnetic field, which is perpendicular to it determined by Fleming's left hand rule. Hold the thumb and first two fingers of the left hand at right angles to each other with the first finger pointing the direction of the field and the second finger in the direction of the current, then the thumb points in the direction of the motion.

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(iii) The direction of current induced in a circuit by changing magnetic flux due to motion of a magnet is determined by Fleming's right-hand rule. If we stretch our right hand in such a way that the thumb, forefinger and central finger remain perpendicular to echo other, so that the forefinger indicates the direction of the magnetic field and the thumb in the direction of motion of conductor. Then the central finger indicates the direction of induced current.

3. Principle : It is based on the principle of electromagnetic induction, which is the process of producing induced current in a coil by relative motion between a magnet and the coil. Function of brushes : The brushes carry the contact from rings to external load resistance.

5. (i) The e.m.f. is maximum when the plane of the coil is parallel to the magnetic field.
(ii) The e.m.f. is zero when the plane of the coil is normal to the magnetic field.
(iii) The e.m.f. will change direction when the plane of coil passes from the position normal to the magnetic field.

6. As the key K is closed, a deflection is observed in the galvanometer for a short while (i.e. a momentary deflection). In other words, the galvanometer needle deflects and returns to zero.
(ii) As the key K is opened, again a momentary deflection (but more) is observed in the opposite direction.
(iii) With the key K closed, if the coil A is moved rapidly towards the coil B, a deflection is obtained in the galvanometer in the direction as in (i) due to increase in magnetic flux through the coil B. But the deflection lasts so long as the coil A moves.
(iv) With the key K closed, if the coil B is moved rapidly towards the coil A, again a deflection is observed in the galvanometer in direction as in (i) due to increase in magnetic flux through the coil B. The deflection lasts so long as the coil B moves.
(v) With the key K closed, if the coils A and B are moved away from each other, a deflection is obtained in the galvanometer in direction as in (ii) due to decrease in magnetic flux through the coil B. The deflection lasts so long as the coils move.

7. The given statement is correct. This is because, according to Lenz's law, the direction of the induced e.m.f. is such as to oppose the cause of production of induced e.m.f.. Thus, the direction of induced e.m.f. is to be determined by the cause of e.m.f..

8. In the case of rapidly moving coil. Because induced e.m.f. will be more in the rapidly moving coil as compared to slow-moving coil. **e.m.f. ∝ work.**

9. (a) When the magnet is rotated about its own axis, there is no change in the magnetic flux linked with the coil. Hence, no induced e.m.f. is produced in the coil.
(b) When the magnet is rotated about an axis perpendicular to its length, the orientation of the magnetic field due to the magnet will change continuously. Due to this, the magnetic flux linked with the coil will also change continuously and it will result in the production of induced e.m.f. in the coil.

10. When the magnet falls, the magnetic flux linked through the metal ring changes, so current is induced in the ring will be in such a direction according to Lenz's law that it opposes the motion of the magnet, so its acceleration will be less than g.

11. In position (i), the coil remain in the magnetic field, so there is no change in magnetic flux in the coil. Therefore, no e.m.f. is induced in the coil.
In position (ii), the coil is coming out of the magnetic field, so the magnetic flux linked with it decreases and hence an e.m.f. is induced in the coil.

12. The magnetic flux linked with the coil increases due to its motion. So by Lenz's law, the induced current in the coil will oppose the increase in magnetic flux. So the magnetic field should be produced in upward direction and the induced current should be anticlockwise.

13. No e.m.f. will be produced between the ends of a metallic pole falling vertically through the plane of magnetic meridian as the falling pole does not cut any magnetic lines of force.

14. The electric current from P to Q is increasing. So by Lenz's law, the induced current in the coil should oppose the increase and hence will be in clockwise direction.

15. Since the south pole of the magnet is approaching towards the loop, so by Lenz's law the induced current in the loop should be in such a direction that it should oppose the approach of the S-pole. So another S-pole should be produced at the near end of the coil. Therefore, the current should be in clockwise direction when viewed from the magnet side.

16. Induced current will be clockwise in both the coils, when viewed from the magnet side as the N-pole is moving away from coil AB so a S-pole should be created at the end B. The S-pole is approching towards CD; hence another S-pole should be produced at the end C to provent its approach.

17. (i) $L = \mu_0 \frac{N^2}{\ell} A$ $\therefore L \mu N^2$

If number of turns (N) of one coil is decreased, self inductance (L) also decreases.
(ii) If an iron core is introduced in the coil, the permeability (m) increases. So self inductance also increases.

18. *Differences between direct and alternating currents:*
Direct current always flows in one direction only whereas alternating current reverses its direction periodically.
Advantage of an alternating current:
Alternating current can be transmitted over a long distances without loss of energy.

Long Answer Questions :

1. Induced e.m.f: When the magnetic flux linked with a coil changes, an e.m.f is induced in the coil. This is called induced e.m.f.

Faraday's law of electromagnetic induction:

1st Law: When the magnetic flux linked with a coil changes, an e.m.f is induced in the coil. It lasts so long as the change in flux continues.

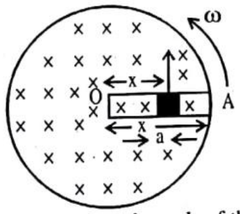
2nd law: The magnitude of induced e.m.f is directly proportional to the rate of change of magnetic flux linked with the coil. It is in the opposite direction of the change of magnetic flux.

$e = \frac{d\phi}{dt}$ [Here proportionality constant =1]

For a coil of N turns, $e = -N\frac{d\phi}{dt}$

Induced e.m.f in a rotating rod:

consider a metallic rod of length l, which is rotating with angular velocity w in a uniform magnetic field B, the plane of rotation being perpendicular to the magnetic field. A rod may be supposed to be formed of a large number of small elements. Consider a small element of length dx at a distance x from centre. If v is the linear velocity of this elements, then area swept out by the element per second = vdx.



∴ E.m.f induced across the ends of the element

$$= dE = B\frac{dA}{dt} = Bv\,dx$$

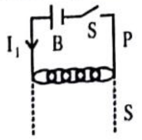
∵ $v = xw$ ∴ $dE = Bxw\,dx$

∴ The e.m.f induced across the rod

$$= \varepsilon = \int_0^{\ell} Bx\omega dx = B\omega\int_0^{\ell} x dx = B\omega\left[\frac{x^2}{2}\right]_0^{\ell} = B\omega\left(\frac{\ell^2}{2} - 0\right)$$

$$\therefore e = \frac{1}{2}B\omega\ell^2$$

2. When current flowing in one of two nearby coil is charged, the magnetic flux linked with the other coil changes, due to which an e.m.f. is induced in the other coil. This phenomenon is called mutual induction. The coil in which current is changed is called primary coil and the coil in which e.m.f. is induced is called secondary coil.



Suppose there are two coils P and S. The current I_1 is flowing in primary coil P due to which an effective magnetic flux ϕ_2 is linked with secondary coil S.

By experiment, $\phi_2 \propto I_1$ ∴ $\phi_2 = MI_1$

Where M is a constant, called coefficient of mutual induction or mutual inductance.

$\therefore M = \frac{\phi_2}{I_1}$ If $I_1 = 1$ A, then $M = \phi_2$

∴ Mutual inductance between two coils is numerically equal to the effective flux linkage with secondary coil, when current flowing in primary coil is 1A.

From Faraday's law,

induced e.m.f in secondary coil $= e_2 = -\frac{d\phi_2}{dt}$

$$\Rightarrow e_2 = -\frac{d}{dt}(MI_1) = -M\frac{dI_1}{dt} \qquad \therefore M = -\frac{e_2}{\frac{dI_1}{dt}}$$

If $dI_1/dt = 1$ A/s ∴ $M = e_2$ (numerically)

∴ Mutual inductance between two coils is numerically equal to the e.m.f. induced with secondary coil, when rate of change of current in primary coil is 1 A/s.

Mutual inductance of a solenoid:

Consider a long solenoid of length l and number of turns N_1. At its central part, a coil of N_2 number of turns is wound. If I_1 is the current flowing in long solenoid, the magnetic field produced within the solenoid is $B_1 = \frac{N_1 I_1}{\ell}$

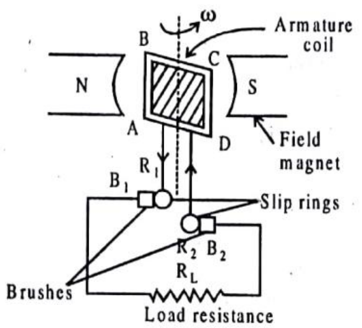
∴ Flux linked with each turn of secondary coil $= \phi_2 = B_1 A$, where A is the cross-sectional area of the solenoid.

∴ Total flux linked with secondary coil of N_2 number of turns $= \phi_2' = N_2 f_2 = N_2 B_1 A = N_2\left(\frac{\mu_o N_1 I_1}{\ell}\right)A$

$$\therefore \phi_2' = \frac{\mu_0 N_1 N_2}{\ell} A I_1$$

$$\therefore \text{Mutual inductance} = M = \frac{\phi_2'}{I_1} = \frac{\mu_o N_1 N_2 A}{\ell}$$

3.



Principle: A dynamo or generator is a device which converts mechanical energy into electrical energy. It is based on the principle of electromagnetic induction.

Construction: It consists of four main parts-

(i) Field magnet: It produces the magnetic field. For a low power dynamo, the magnetic field in generated by a permanent magnet but for a large power dynamo, the magnetic field is produced by an electromagnet.

(ii) Armature: It consists of a large number of turns of insulated copper wire on a soft iron core. It can revolve round the axis between the two poles of the field magnet. The soft iron core provides support to the coils and increases the magnetic field through the coil.

(iii) Slip rings: The slip rings R_1 and R_2 are two metal rings to which the ends of the armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.

(iv) Brushes (B_1 and B_2): These are flexible metal plates or carbon rods which are fixed and constantly touch the revolving rings. The output current in external load resistance R_1 is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked the coil changes and the current is induced in the coil. The direction of current is given by Flemming's left hand rule. It remains same during the first half turn of the armature. During the second half revolution, the direction of current is reversed.

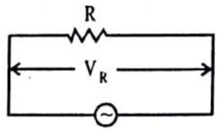
If N is the number in the coil, f is the frequency of rotation, A is the area of the coil and B is the magnetic field intensity then induced e.m.f..

$$e = -\frac{d\phi}{dt} = \frac{d}{dt}(NBA\cos 2pft) = 2pNBAf\sin 2pft$$

Therefore, the e.m.f. produced is alternating in nature and the current is also alternating.

Current produced in a.c. generator can not be measured by moving coil galvanometer, because average value of a.c. over full cycle is zero.

4.

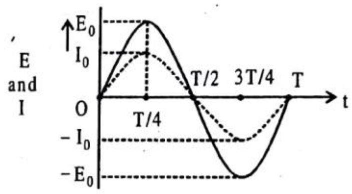


Let V_R be the instantaneous voltage drop across R.
E is the applied alternating e.m.f. to the circuit. E_0 is the maximum voltage.

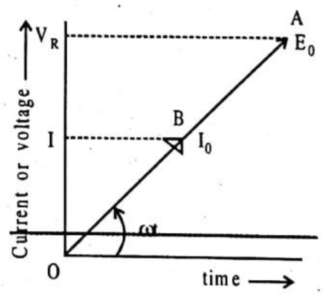
$$\therefore \quad E = E_0 \sin \omega t = IR \quad \therefore \quad I = \frac{E_0}{R}\sin \omega t = I_0 \sin \omega t$$

where $I_0 = \frac{E_0}{R}$ = Maximum value of current.

$\therefore$ Current and voltage are in phase with each other.



Graphical representation of voltage and current



Phasor Diagram

The reflections of E_0 and I_0 on y-axis gives the instantaneous voltage drop across R (V_R). ωt is called the phase angle.

5. The obstruction posed by a circuit to the flow of a.c. is called its impedance (Z).

$$Z = \frac{V}{I} = \frac{\text{rms applied voltage}}{\text{rms current}}$$

It's S.I. unit is ohm.

Series L – C – R circuit:

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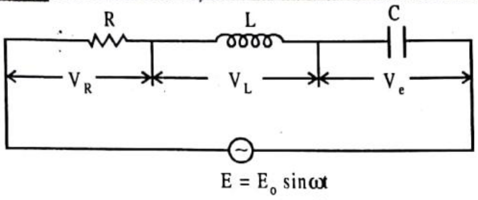
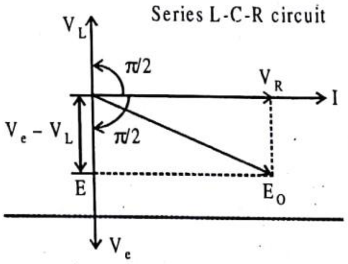


Series L-C-R circuit



Phasor diagram

Consider a resistance (R), inductance (L) and capacitance (C) are connected in series and an alternating source of voltage $E = E_0 \sin \omega t$ is applied across it. Since they are connected in series, the current I flowing through all of them is same.

Let the voltage across the resistance R is V_R, voltage across inductance L is V_L and voltage across capacitance C is V_C. Since the current and the voltage across the resistor are in phase so they are represented by a phasor in the same direction. The voltage (V_L) across the inductor leads current by an angle $\pi/2$ while the voltage (V_C) across the capacitor lags behind the current by $\pi/2$. V_L and V_C are in opposite direction, so their resultant potential difference $= V_C - V_L$ (where $V_C > V_L$)

So the phasors V_R and $(V_C - V_L)$ are perpendicular to each other. The resultant of them is equal to E, the applied instantaneous voltage.

$$\therefore\ E^2 = V_R^2 + (V_C - V_L)^2 \Rightarrow E = \sqrt{V_R^2 + (V_C - V_L)^2}$$

But $V_R = IR$, $V_C = X_C I$ and $V_L = X_L I$ where $X_C = \dfrac{1}{\omega C}$

and $X_L = \omega L$.

$$\therefore\ E = \sqrt{I^2R^2 + (IX_C - IX_L)^2} = I\sqrt{R^2 + (X_C - X_L)^2}$$

$$\Rightarrow Z = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$

The phase difference between voltage and current I can be given by the phase angle φ,

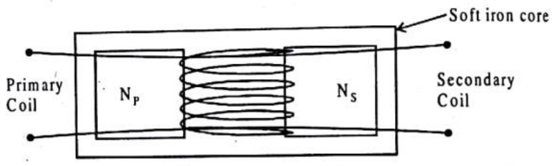
where, $\tan\varphi = \dfrac{X_C - X_L}{R}$

For resonance, $X_C - X_L = 0 \therefore \varphi = 0$

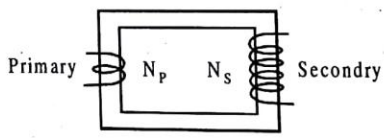
Also, $\dfrac{1}{\omega C} = \omega L \Rightarrow \omega^2 = \dfrac{1}{LC}$

$\therefore$ Resonant frequency $= \omega_r = \dfrac{1}{\sqrt{LC}}$

6. The first arrangement is when two coils on top of each other.



The second arrangement is where two coils are wound on separate limbs of the core.



Ratio of output voltage to input voltage, $\dfrac{E_S}{E_P} = \dfrac{N_S}{N_P}$

Ratio of output current to input current, $\dfrac{I_S}{I_P} = \dfrac{N_P}{N_S}$

Energy losses in a transformer

1. Copper loss: Energy is lost as heat from the copper coils due to joule heating in the conducting wires.
2. Iron loss: Energy is lost as heat from the iron core of the transformer due to eddy current produced in the core. It can be minimised by the laminated core.
3. Leakage of magnetic flux: Due to this loss, magnetic flux linked with the primary will not be equal to that linked with secondary.
4. Hysteresis loss: Loss of heat energy due to repeated magnetisation and demagnetisation of the iron core.
5. Magnetostriction: Humming noise of a transformer.

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Exercise 2

MULTIPLE CHOICE QUESTIONS :

1.	(b)	2.	(c)	3.	(d)	4.	(a)
5.	(c)	6.	(d)	7.	(b)	8.	(b)
9.	(a)	10.	(b)	11.	(b)	12.	(c)
13.	(d)	14.	(c)	15.	(d)	16.	(c)
17.	(d)	18.	(d)	19.	(a)	20.	(a)
21.	(a)	22.	(c)	23.	(a)	24.	(b)
25.	(b)	26.	(c)	27.	(b)	28.	(b)
29.	(d)	30.	(c)	31.	(b)	32.	(b)
33.	(b)	34.	(c)	35.	(b)	36.	(a)
37.	(c)	38.	(d)	39.	(b)	40.	(b)
41.	(c)	42.	(b)	43.	(c)	44.	(c)
45.	(a)	46.	(d)	47.	(c)	48.	(d)
49.	(b)	50.	(c)	51.	(d)	52.	(c)
53.	(d)	54.	(d)	55.	(c)	56.	(b)
57.	(b)	58.	(a)	59.	(c)	60.	(d)
61.	(a)	62.	(b)	63.	(d)	64.	(b)
65.	(b)	66.	(b)	67.	(a)	68.	(a)
69.	(b)	70.	(b)	71.	(a)		

MORE THAN ONE CORRECT :

1.	(a, d)	2.	(a, b, d)	3.	(a, b)
4.	(a, b)	5.	(b, c, d)	6.	(b, c, d)
7.	(c, d)	8.	(a, b)	9.	(b, d)
10.	(b, c, d)	11.	(a, b, c)		

FILL IN THE PASSAGE :

I. 1. self induction, 2. gradually, 3. increases, 4. oppose, 5. magnetic flux, 6. induced, 7. opposite

II. 1. alternating, 2. primary, 3. secondary, 4. transformation 5. transformer

PASSAGE BASED QUESTIONS :

Passage:I

1. (b) 2. (a) 3. (a)

Passage:II

1. (a) 2. (d) 3. (c)

Passage:III

1. (d) 2. (c) 3. (b)
4. (b) 5. (a)

ASSERTION & REASON :

1. (b)
2. (a) Lenz's law (that the direction of induced e.m.f. is always such as to oppose the change that cause it) is direct consequence of the law of conservation of energy.
3. (b)
4. (b)
5. (d)
6. (b) 7. (b) 8. (c)

MULTIPLE MATCHING QUESTIONS :

1. A-p, r, s; B-q; C-t; D-p, r, s

$e = -\frac{d\phi}{dt}$. In case (A), flux changes wrt time in case (B), flux is constant.

In case (C), $e = Bv\ell$, $q = CBv\ell$,

$\frac{dq}{dt} = CB\ell\frac{dv}{dt} = +ve\ const.$

In Case D, Angle between $\vec{B}$ and $\vec{A}$ changes with time hence i changes with time.

HOTS SUBJECTIVE QUESTIONS :

1. Relative permeability $= m_r = \frac{L_{medium}}{L_{air}} = \frac{10\,mH}{0.01\,mH}$

$\therefore\ m_r = 1000.$

2. Since the current in wire PQ is steady (constant) so $\frac{d\phi}{dt} = 0$

$\therefore$ Induced e.m.f. and hence induced current is zero.

3. As soon as the switch S is closed, an e.m.f. is induced in the ring R and it is repelled.
4. Slipring arrangement in an a.c generator is replaced by split ring arrangement in the d.c generator.
5. Efficiency, $\eta = \frac{E}{V} = \frac{\text{back emf}}{\text{emf of battery}}$
6. Current at resonance $I = \frac{V}{R}$.

$\therefore$ Voltage across inductor, $V_L = I.X_L = \frac{V}{R}.\omega L = \frac{V}{R}.2\pi\nu L$

7. There are three assumptions:–
   (i) The primary resistance and current are small.
   (ii) The same flux links both the primary and the secondary as very little flux escapes from the core.
   (iii) The secondary current is small.
8. The bulb will glow brighter. As capacitative reactance is

$X_C = \frac{1}{2\pi\nu C}$.

The value of X_C decreases with increase in frequency and hence the current through the bulb increases.

9. No, a circuit containing an inductor L and capacitor C and no resistance exhibits free oscillations.
10. The impedance of R – L circuit $= Z = \sqrt{R^2 + \omega^2 L^2}$

As $\omega = 2\pi f$, so when frequency increases, ω will increase and Z will also increase.

$\therefore$ current $= \frac{E}{Z}$ will decrease.

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11. Inductive reactance = $X_L = wL = 2pfL$
If f increases, X_L will increase.

Capacitive reactance = $X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$

If f increases, X_L will decrease.

12. The phase difference is 180°.

13. The metal detector works on the principle of resonance in ac circuits.

14. At resonance, $\phi = 0$, therefore $\cos \phi = 1$.

15. A.C. ammeter works on the principle of heating effect. $(H \propto I^2R)$

16. When the magnetic flux linked with a conductor changes, a current is induced in the body of the conductor called eddy current. Eddy current is used for electromagnetic damping in dead beat galvanometer. It is used in Induction furnace to produce lot of heat sufficient to melt a metal.

17. (i) When the distance between the coils is increased the magnetic flux linked between them decreases as magnetic lines of force tend to diverge with distance. So mutual inductance also decreases.

(ii) If the number of turns in each coil is decreased then also mutual inductance decreases as mutual inductance is directly proportional to the number of turns.

18. When the switch is closed the flux associated with L changes, an e.m.f. is induced in L which will oppose the growth of current in Q. But no such induced e.m.f. will be produced in R. So P will light up faster.

19. (i) When coil A is placed parallel to B and near to it, due to mutual induction an e.m.f is induced in B and the bulb lights up.

(ii) When the coil B is moved upwards, distance between A and B increases. Hence the magnetic flux linked with B decrease and mutual induction decreases and hence the bulb gets dimmer.

20. In fig. (a), no change in magnetic flux takes place. Hence no e.m.f is induced in the coil.

In fig. (b), an e.m.f is induced in the coil as the magnetic flux is changed.

21. The direction of induced current will be anti-clockwise i.e. along PSRQP. This is given by Flemming's right hand rule.

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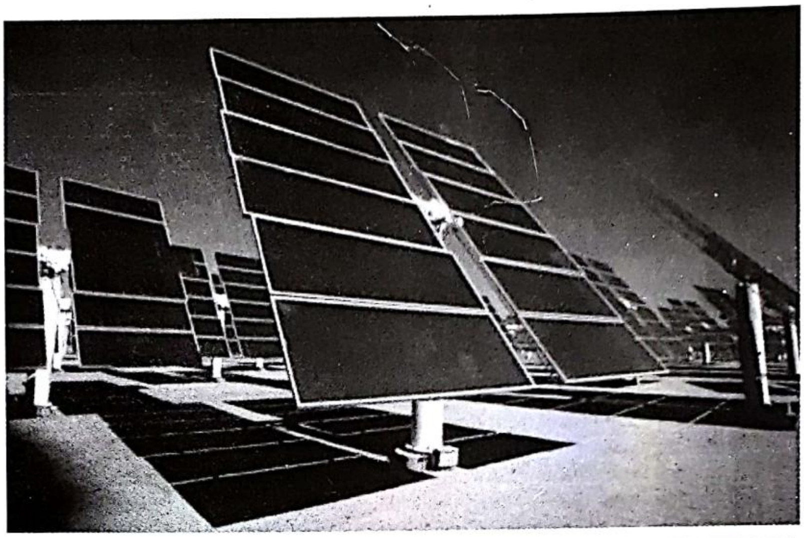
chapter 8



SOURCES OF ENERGY

Introduction

We use energy to do work. Energy lights our cities. Energy powers our vehicles, trains, planes and rockets. Energy warms our homes, cooks our food, plays our music, gives us pictures on television. Energy powers machinery in factories and tractors on a farm. Energy from the sun gives us light during the day. It dries our clothes when they're hanging outside on a clothes line. It helps plants grow. Energy stored in plants is eaten by animals, giving them energy. And predator animals eat their prey, which gives the predator animal energy. Everything we do is connected to energy in one form or another. Energy is defined as: "the ability to do work."

When we eat, our bodies transform the energy stored in the food into energy to do work. When we run or walk, we "burn" food energy in our bodies. When we think or read or write, we are also doing work. Cars, planes, light bulbs, boats and machinery also transform energy into work. Work means moving something, lifting something, warming something, lighting something. All these are a few of the various types of work. But where does energy come from? There are many sources of energy. Energy is an important part of our daily lives.

Various forms of energy includes: Electricity, Biomass Energy - energy from plants, Geothermal Energy, Fossil Fuels - Coal, Oil and Natural Gas, Hydro Power and Ocean Energy, Nuclear Energy, Solar Energy, Wind Energy.

All forms of energy are stored in different ways, in the energy sources that we use every day. These sources are divided into two groups – renewable (an energy source that can be replenished in a short period of time) and non-renewable (an energy source that we are using up and cannot recreate in a short period of time). Renewable and non-renewable energy sources can be used to produce secondary energy sources including electricity.

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GOOD SOURCE OF ENERGY

A good source of energy would be one which would do a large amount of work per unit volume or mass, be easily accessible, be easy to store and transport, and perhaps most importantly, be economical. So evaluation Criteria for source of energy are: Capital Costs, Operating Costs, Efficiency, Is it renewable? Energy Storage Requirements, Pollution, Environmental Modification, Levelized cost to the consumer, Feasibility on Large Scale, Unit Capacity.

CONVENTIONAL SOURCES OF ENERGY

Fossil Fuels

Fossil fuels are hydrocarbon based natural resources that were formed over 300 hundred millions of years ago by the fossilization of prehistoric plants and animals. There are three major forms of fossil fuels: coal, oil and natural gas. We have learned to harness the energy released from these fossil fuels during combustion in order to meet our energy needs. Fossil fuels are a common source of energy we use everyday. They are used to generate the electricity that runs our household appliances, fuel the motors of our cars, and heat our homes. Fossil fuels are currently essential to providing the energy needs of our everyday lives.

Although the supplies of these fossil fuels are vast, they are not unlimited. Fossil fuels are depleting at an alarming rate. They are a non-renewable resource and we are consuming vast quantities of them every day. Varying estimates project a complete depletion of oil and natural gas within anywhere from 40-100 years. Coal is the most abundant of the three and will last for about another 230 years. It is very likely that within our life times that one of these fossil fuels, if not more, will be completely consumed from the planet. And more important, the earth's atmosphere and biosphere may not survive the environmental impact of burning such enormous amounts of these fuels. Global warming is directly associated with the increase in greenhouse gases produced from the burning of fossil fuels. Carbon stored over millions of years is being released in a matter of decades, disrupting the earth's carbon cycle in unpredictable ways.

But fossil fuels are not the only source of energy, and burning fuel is not the only way to produce heat and motion. Renewable energy offers us a better way. Some energy sources are "renewable" because they are naturally replenished, because they can be managed so that they last forever, or because their supply is so enormous that they can never be meaningfully depleted by humans. Moreover, renewable energy sources have much smaller environmental impacts than fossil and nuclear fuels.

THERMAL POWER PLANT

A thermal power station comprises all of the equipment and systems required to produce electricity by using a steam generating boiler fired with fossil fuels or biofuels to drive an electrical generator. Such power stations are most usually constructed on a very large scale and designed for continuous operation.

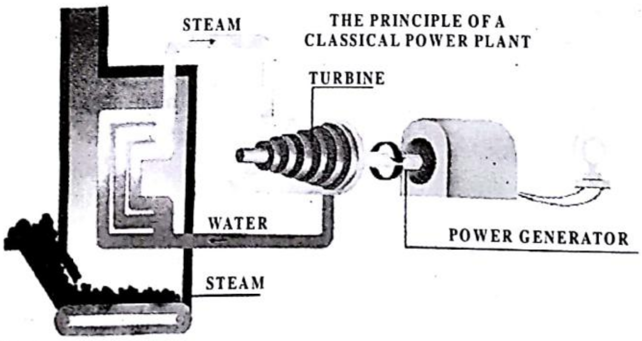

Fig : 8.2

Electricity generation in thermal power plants includes firing of coal, gas or mazout. Steam is produced in a boiler, and it drives a turbine connected to a generator. Heat energy is converted to electric energy within the so-called steam cycle.

A thermal plant comprises several separate production units with specific size and power.

A conventional power plant consists of a boiler room, interposed machine room, machine room, electric power output, and auxiliary operations (coal loading, water treatment, water management, back fuel cycle, etc.). The following types of thermal power plants exist: condensating, whose main focus is generation of electricity, thermal plants whose main focus is combined generation of electricity and heat.

In a conventional condensating type thermal power plant, the electricity generation part is dominated by arrangement in production units. Every production unit of the power plant represents a separate generation entity a separate power plant. By the method of

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combustion, solid fuel firing boilers are classified into grate, granulation, fusion, and fluidized-bed type. Boilers firing solid and gas fuels are in addition to the above mentioned boilers.

Every power plant unit may be operated independently. The principle of operation is quite simple. Stockpile coal is moved by a bulldozer into an underground bunker, wherefrom it is taken by a coaling belt into a coal holder located at every boiler. The coal is gradually dried and ground to powder that is subsequently fired in the boiler. Pipe or membrane type evaporators are located in the boiler walls; there, water turns into steam and the steam generated (of a high temperature and pressure) is led to steam cylinder, wherefrom it is led through pre-heaters and postheaters via steam distribution pipes to turbine blades. The turbine is connected to a generator.

Turbine and electric generator comprises a single train – turbogenerator. In the turbogenerator, heat energy is converted into electric energy. Electric energy thus produced is led through a system of transformers and distribution grid to end-consumers. Having delivered its energy to turbine blades, the steam condensates in heat exchanger – condenser. Upon passing the turbine, the steam temperature and pressure get reduced. The steam changes its state and turns into water called condensate. Large quantities of cooling energy are needed for steam to condensate. Surface water from a stream or a reservoir is used for cooling. If there is a plenty of cooling water, flow-through system of cooling is used; circulation system of cooling with water being cooled in cooling towers is used for places with insufficient supply of cooling water.

On their way to the stack, flue gases produced during the firing of coal heat water in economizer, which is a heat exchanger for combustion gas. Cooled stack gases then pass through electrostatic filters where ash is caught, and continue to the stack.

To reduce nitrogen and sulfur oxides, desulfurization and denitrification equipment are installed to conventional boilers. For fluidized-bed boilers, desulfurization and denitrification is resolved directly by the boiler technology.

You may have heard about NTPC largest thermal power generating company of India.

In 1995, India had an installed electrical generating capacity of 81 gigawatts (GW), of which 73 percent was thermal. This is the world's sixth largest capacity and equal to that of France and the United Kingdom. India's power sector has grown at an average annual rate of 8.8 percent since 1950, when installed capacity was only 2.3 GW. About 85 percent of the country was electrified in 1995. Despite the dramatic increase in power generation capabilities, India has been unable to keep up with its domestic demand for electricity. India's electricity is generated overwhelmingly by coal (70 percent). Hydroelectricity ranks a distant second (about 25 percent), followed by natural gas, nuclear power, oil, and renewables.

HYDRO POWER PLANTS

When it rains in hills and mountains, the water becomes streams and rivers that run down to the ocean. The moving or falling water can be used to do work. Energy, you'll remember is the ability to do work. So moving water, which has kinetic energy, can be used to make electricity.

For hundreds of years, moving water was used to turn wooden wheels that were attached to grinding wheels to grind (or mill) flour or corn. These were called grist mills or water mills.

Hydro means water. Hydro-electric means making electricity from water power. In fact, humans have been using the energy in moving water for thousands of years. Today hydroelectric power is the largest source of renewable power worldwide. A quarter of our energy requirement in India is met by hydro power plants.

Hydroelectric power uses the kinetic energy of moving water to make electricity. Dams can be built to stop the flow of a river. Water behind a dam often forms a reservoir.

The water behind the dam flows through the intake and into a pipe called a penstock.

The principle of the operation of hydroelectric power plants is conversion of mechanical into electric energy. Water stream passes stable turbine vanes and thus directed water stream hits water turbine blades of the turbine runner curved in an opposite direction; in this way, the blades are turned, and receive mechanical energy from water. Mechanical energy of water is converted into mechanical energy of the shaft, and subsequently to electric energy in electric generators. Electric generators of hydroelectric power plants convert mechanical energy to electric energy with a high efficiency. In synchronous generators, electric energy is generated by inducing rotating magnetic field of the rotor into stable generator stator coil. To generate magnetic field of the rotor, excitation direct current is needed generated in generator exciter.

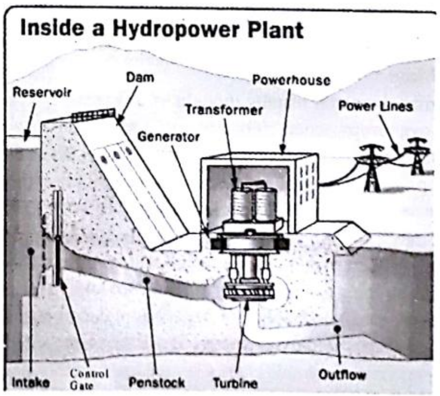

Fig : 8.3

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Hydroelectric generation can also work without dams, in a process known as diversion, or run-of-the-river. Portions of water from fast-flowing rivers, often at or near waterfalls, can be diverted through a penstock to a turbine set in the river or off to the side. The generating stations at Niagara Falls are an example of diversion hydropower. Another run-of-the-river design uses a traditional water wheel on a floating platform to capture the kinetic force of the moving river. While this approach is inexpensive and easy to implement, it doesn't produce much power. The entire Amazon River, if harnessed this way, would produce only 650 MW of power.

Another type of hydropower, though not a true energy source, is pumped storage. In a pumped storage plant, water is pumped from a lower reservoir to a higher reservoir during off-peak times, using electricity generated from other types of energy sources. When the power is needed, it is released back into the lower reservoir through turbines. Inevitably, some power is lost, but pumped storage systems can be up to 80 percent efficient. Future increases in pumped storage capacity could result from the integration of hydropower and wind power technologies. Researchers believe that hydropower may be able to act as a battery for wind power by storing water during high wind periods.

Although an inexpensive and nonpolluting energy resource, the environmental damage caused hydropower can be serious. The most obvious effect is that fish are blocked from moving up and down the river, but there are many more problems.

When a dam is constructed, a river habitat is replaced by a lake habitat. While this may not sound so bad – fish and birds like lakes, too it can cause a number of environmental problems. Dams can create large reservoirs submerging what used to be dry land, producing many problems. Population density is typically higher along rivers, leading to mass dislocation of urban centers. Opposition to the construction of Tehri Dam on the river Ganga and Sardar Sarovar project on the river Narmada are due to such problems.

Wildlife habitats destroyed by reservoirs can be especially valuable. Another problem can occur when the land area behind the dam is flooded without proper preparation. Later, as the plants and trees that were submerged began to rot, they reduced the oxygen content of the water, killing off the plants and fish in the water. Moreover, the rotting plants gave off large quantities of methane, a powerful global warming gas.

Impoundments used for hydropower can cause many other effects on water quality and aquatic life. Rivers and lakes can be filled with sediment from erosion. Water falling over spillways can force air bubbles into the water, which can be absorbed into fish tissue, ultimately killing the fish. By slowing down rivers, the water can become stratified, with warm water on top and cold water on the bottom. Since the cold water is not exposed to the surface, it loses its oxygen and becomes uninhabitable for fish.

The risk of a dam breaking should also not be ignored. The great Johnstown flood in Pennsylvania was the result of a dam break (although not a hydroelectric dam); 2,000 people were killed. In northern India and Nepal, in the Himalayas, huge hydroelectric projects are planned that would create large reservoirs in a geographically unstable region. Frequent earthquakes make the dam a risky venture for heavily populated areas downstream. This is compounded by the fear that large, heavy reservoirs would put additional pressure on the plates in the region, causing even more earthquakes. Finally, breakage could also result from war or terrorism, as dams have been considered potential military targets in the past. The environmental and social effects of hydropower can be immense. But while hydropower has its problems, it can still be a safe and sustainable source of electricity if proper measures are taken. By upgrading and improving the equipment at plants, by increasing fish-friendly efforts at dams, and by improving run-of-the-river turbine technology, it may be possible to reduce the environmental effects of hydropower. Nonetheless, remediation may be impossible at some sites, and wild rivers should be unshackled.

It is also important to compare the environmental effects of hydropower with alternatives. The damage to aquatic habitat from dams may be significant, but acid rain, nitrogen deposition, and thermal pollution from coal plants also lead to aquatic damage, as well as to air pollution and global warming.

Improvements in the Technology for using Conventional Sources of Energy

BioMass

Biomass is matter usually thought of as garbage. Some of it is just stuff lying around–dead trees, tree branches, yard clippings, left-over crops, wood chips and bark and sawdust from lumber mills. It can even include used tires and livestock manure.

Your trash, paper products that can't be recycled into other paper products, and other household waste are normally sent to the dump. Your trash contains some types of biomass that can be reused. Recycling biomass for fuel and other uses cuts down on the need for "landfills" to hold garbage.

This stuff nobody seems to want can be used to produce electricity, heat, compost material or fuels. Composting material is decayed plant or food products mixed together in a compost pile and spread to help plants grow.

A similar thing can be done at animal feed lots. In places where lots of animals are raised, the animals - like cattle, cows and even chickens-produce manure. When manure decomposes, it also gives off methane gas similar to garbage. This gas can be burned right at the farm to make energy to run the farm.

Biomass is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into

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carbohydrates, complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burned, they turn back into carbon dioxide and water and release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably—with only as much used as is grown the battery will last indefinitely.

A number of noncombustion methods are available for converting biomass to energy. These processes convert raw biomass into a variety of gaseous, liquid, or solid fuels that can then be used directly in a power plant for energy generation. The carbohydrates in biomass, which are comprised of oxygen, carbon, and hydrogen, can be broken down into a variety of chemicals, some of which are useful fuels. This conversion can be done in three ways:

(1) Thermochemical : When plant matter is heated but not burned, it breaks down into various gases, liquids, and solids. These products can then be further processed and refined into useful fuels such as methane and alcohol. Biomass gasifiers capture methane released from the plants and burn it in a gas turbine to produce electricity. Another approach is to take these fuels and run them through fuel cells, converting the hydrogen-rich fuels into electricity and water, with few or no emissions.

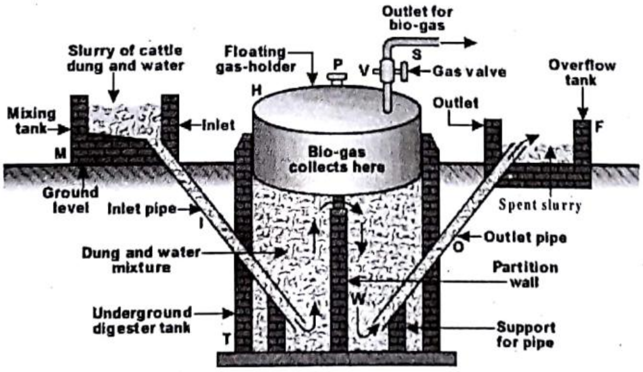
(2) Biochemical : Bacteria, yeasts, and enzymes also break down carbohydrates. Fermentation, the process used to make wine, changes biomass liquids into alcohol, a combustible fuel. A similar process is used to turn corn into grain alcohol or ethanol, which is mixed with gasoline to make gasohol. Also, when bacteria break down biomass, methane and carbon dioxide are produced. This methane can be captured, in sewage treatment plants and landfills, for example, and burned for heat and power.

(3) Chemical : Biomass oils, like soybean and canola oil, can be chemically converted into a liquid fuel similar to diesel fuel, and into gasoline additives. Cooking oil from restaurants, for example, has been used as a source to make "biodiesel" for trucks. (A better way to produce biodiesel is to use algae as a source of oils.)

Bio gas : Bio gas is made from organic waste matter after it is decomposed. The decomposition breaks down the organic matter, releasing various gases. The main gases released are methane, carbon dioxide, hydrogen and hydrogen sulphide. Bacteria carry out the decomposition or fermentation. The conditions for creating bio gas has to be anaerobic that is without any air and in the presence of water. The organic waste matter is generally animal or cattle dung, plant wastes, etc. These waste products contain carbohydrates, proteins and fat material that are broken down by bacteria. The waste matter is soaked in water to give the bacteria a proper medium to grow. Absence of air or oxygen is important for decomposition because bacteria then take oxygen from the waste material itself and in the process break them down.

There are two types of bio gas plants that are used in India. These plants mainly use cattle dung called "gobar" and are hence called gobar gas plant. Generally a slurry is made from cattle dung and water, which forms the starting material for these plants. The two types of bio gas plants are : (1) Floating gas-holder type (2) Fixed dome type

Floating gas holder type of plant : The diagram below shows the details of a floating gas holder type of bio gas plant.



Floating gas-holder type bio-gas plant.

Fig : 8.4

A well is made out of concrete. This is called the digester tank T. It is divided into two parts. One side has the inlet, from where slurry is fed to the tank. The tank has a cylindrical dome H made of stainless steel that floats on the slurry and collects the gas generated. Hence the name given to this type of plant is floating gas holder type of bio gas plant. The slurry is made to ferment for about 50 days. As more gas is made by the bacterial fermentation, the pressure inside H increases. The gas can be taken out through outlet pipe V. The decomposed matter expands and overflows into the next chamber in tank T. This is then removed by the outlet pipe to the overflow tank and is used as manure for cultivation purposes.

Fixed dome type of plant : The diagram below shows the details of a fixed dome type of bio gas plant.

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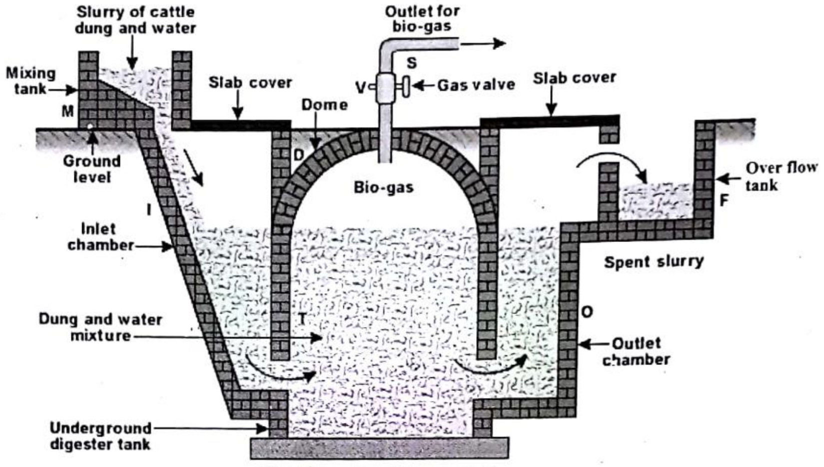

Fixed-dome type bio-gas plant.

Fig : 8.5

A well and a dome are made out of concrete. This is called the digester tank T. The dome is fixed and hence the name given to this type of plant is fixed dome type of bio gas plant. The function of the plant is similar to the floating holder type bio gas plant. The used slurry expands and overflows into the overflow tank F.

Bio gas is used as cooking fuel as it contains up to 75% methane and burns without smoke, has high calorific value, can be piped into kitchens directly from a plant and is cheaper in cost.

Bio gas can be used to run electric engines such as pumps, as they cause less air pollution.

Bio gas can be used for street lighting as they do not cause any smoke and the illumination obtained can be made to be quite adequate.

WIND ENERGY

Along with sun, it was the air, which showed man its power. Even before the solar energy, it was the wind energy that man used for his work. Initially, it was used in two main ways; to drive wind mills on land and to drive sailing vessels at sea. The first use of windmills were to grind foods grains and to run pumps to irrigate. Farmers have been using wind energy for many years to pump water from wells using windmills. Now with the advancement of science and technology, we have windmills generating electricity. Naturally, now this energy can be used for many more works.

Fig : 8.6 Wind mill pump

Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates.

During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water.

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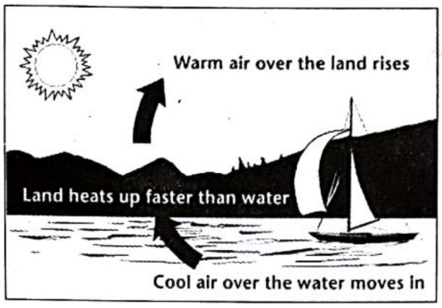

Fig : 8.7

In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles.

WHAT MAKES THE WIND BLOW?

Wind is the response of the atmosphere to uneven heating conditions. This creates pressure differences in the atmosphere causing the wind to blow from regions of high atmospheric pressure to low atmospheric pressure. The larger the pressure difference the greater the wind velocity.

Air pressure represents the amount of atmosphere that is pressing down on the surface of the earth at some point, as shown here:

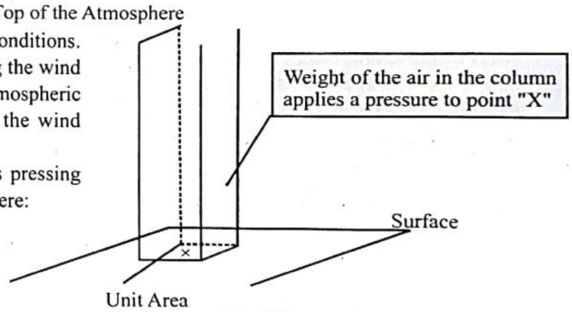

Fig. 8.8

Pressure differences yield wind (bulk motion of the air). Wind can be used to do work. The kinetic energy of the wind can be changed into other forms of energy, either mechanical energy or electrical energy. Infact Wind energy is the fastest growing source of electricity in the world.

Harnessing the wind is one of the cleanest, most sustainable ways to generate electricity. Wind power produces no toxic emissions and none of the heat trapping emissions that contribute to global warming. This, and the fact that wind power is one of the most abundant and increasingly cost-competitive energy resources, makes it a viable alternative to the fossil fuels that harm our health and threaten the environment.

Blowing wind spins the blades on a wind turbine – just like a large toy pinwheel. This device is called a wind turbine and not a windmill. A windmill grinds or mills grain, or is used to pump water.

The blades of the turbine are attached to a hub that is mounted on a turning shaft. The shaft goes through a gear transmission box where the turning speed is increased. The transmission is attached to a high speed shaft which turns a generator that makes electricity. If the wind gets too high, the turbine has a brake that will keep the blades from turning too fast and being damaged.

Fig : 8.9

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In order for a wind turbine to work efficiently, wind speeds usually must be above 12 to 14 miles per hour. Wind has to be this speed to turn the turbines fast enough to generate electricity. The turbines usually produce about 50 to 300 kilowatts of electricity each. A kilowatt is 1,000 watts (kilo means 1,000). You can light ten 100 watt light bulbs with 1,000 watts. So, a 300 kilowatt (300,000 watts) wind turbine could light up 3,000 light bulbs that use 100 watts.

Once electricity is made by the turbine, the electricity from the entire wind farm is collected together and sent through a transformer. There the voltage is increase to send it long distances over high power lines.

The wind resource–how fast it blows, how often, and when–plays a significant role in its power generation cost. The power output from a wind turbine rises as a cube of wind speed. In other words, if wind speed doubles, the power output increases eight times. Therefore, higher-speed winds are more easily and inexpensively captured.

Wind speeds are divided into seven classes–with class one being the lowest, and class seven being the highest. A wind resource assessment evaluates the average wind speeds above a section of land (usually 50 meters high), and assigns that area a wind class. Wind turbines operate over a limited range of wind speeds. If the wind is too slow, they won't be able to turn, and if too fast, they shut down to avoid being damaged. Wind speeds in classes three (6.7 – 7.4 meters per second (m/s)) and above are typically needed to economically generate power. Ideally, a wind turbine should be matched to the speed and frequency of the resource to maximize power production.

The more the wind blows, the more power will be produced by wind turbines. But, of course, the wind does not blow consistently all the time. The term used to describe this is "capacity factor," which is simply the amount of power a turbine actually produces over a period of time divided by the amount of power it could have produced if it had run at its full rated capacity over that time period.

A more precise measurement of output is the "specific yield." This measures the annual energy output per square meter of area swept by the turbine blades as they rotate. Overall, wind turbines capture between 20 and 40 percent of the energy in the wind. So at a site with average wind speeds of seven m/s, a typical turbine will produce about 1,100 kilowatt-hours (kWh) per square meter of area per year. If the turbine has blades that are 40 meters long, for a total swept area of 5,029 square meters, the power output will be about 5.5 million kWh for the year. An increase in blade length, which in turn increases the swept area, can have a significant effect on the amount of power output from a wind turbine.

THE MECHANICS OF WIND TURBINES

Modern electric wind turbines come in a few different styles and many different sizes, depending on their use. The most common style, large or small, is the "horizontal axis design" (with the axis of the blades horizontal to the ground). On this turbine, two or three blades spin upwind of the tower that it sits on.

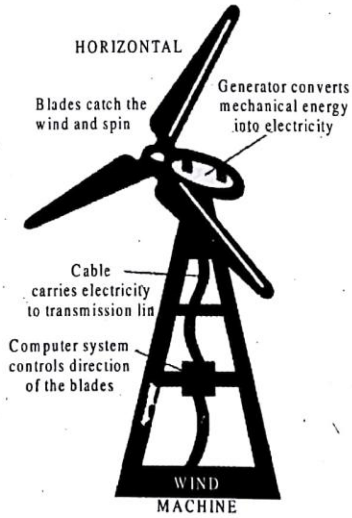

Fig : 8.10

Small wind turbines are generally used for providing power off the grid, ranging from very small, 250-watt turbines designed for charging up batteries on a sailboat, to 50-kilowatt turbines that power dairy farms and remote villages. Like old farm windmills, these small wind turbines have tail fans that keep them oriented into the wind.

Large wind turbines, most often used by utilities to provide power to a grid, range from 250 kilowatts up to the enormous 3.5 to 5 MW machines that are being used offshore. Today, the average land-based wind turbines have a capacity of 1.5 MW. Large turbines sit on towers that can be anywhere from 50 to 100 meters tall, and have blades that range from 30 to 50 meters long.

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Utility-scale turbines are usually placed in groups or rows to take advantage of prime windy spots. Wind "farms" like these can consist of a few or hundreds of turbines, providing enough power for tens of thousands of homes.

From the outside, horizontal axis wind turbines consist of three big parts: the tower, the blades, and a box behind the blades, called the nacelle. Inside the nacelle is where most of the action takes place, where motion is turned into electricity. Large turbines don't have tail fans; instead they have hydraulic controls that orient the blades into the wind.

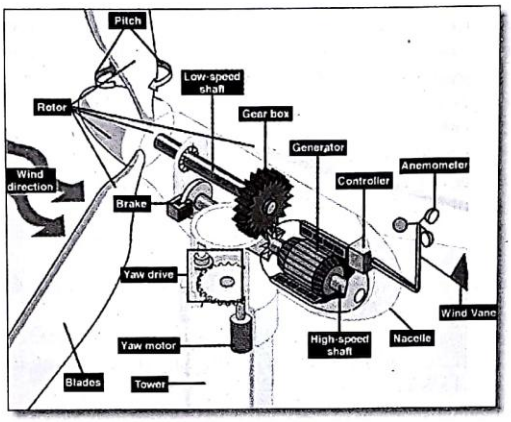

Fig : 8.11

In the most typical design, the blades are attached to an axle that runs into a gearbox. The gearbox, or transmission, steps up the speed of the rotation, from about 50 rpm up to 1,800 rpm. The faster spinning shaft spins inside the generator, producing AC electricity. Electricity must be produced at just the right frequency and voltage to be compatible with a utility grid. Since the wind speed varies, the speed of the generator could vary, producing fluctuations in the electricity. One solution to this problem is to have constant speed turbines, where the blades adjust, by turning slightly to the side, to slow down when wind speeds gust. Another solution is to use variable-speed turbines, where the blades and generator change speeds with the wind, and sophisticated power controls fix the fluctuations of the electrical output. A third approach is to use low-speed generators. An advantage that variable-speed turbines have over constant-speed turbines is that they can operate in a wider range of wind speeds. All turbines have upper and lower limits to the wind speed they can handle: if the wind is too slow, there's not enough power to turn the blades; if it's too fast, there's the danger of damage to the equipment. The "cut in" and "cut out" speeds of turbines can affect the amount of time the turbines operate and thus their power output.

Denmark is called the country of 'winds'. More than 25% of their electricity needs are generated through a vast network of windmills. In terms of total output, Germany is the leader, while India is ranked fifth in harnessing wind energy for the production of electricity. It is estimated that nearly 45,000 MW of electrical power can be generated if India's wind potential is fully exploited. The largest wind energy farm has been established near Kanyakumari in Tamil Nadu and it generates 380 MW of electricity.

The world's largest wind farm, the Horse Hollow Wind Energy Center in Texas, has 421 wind turbines that generate enough electricity to power 230,000 homes per year.

ALTERNATIVE OR NON-CONVENTIONAL SOURCES OF ENERGY

Solar energy (power from the sun is free and inexhaustible)

The energy obtained from the sun is called solar energy. The inner temperature of the sun is very high (10^7k). At this high temperature the nucleus of lightest gas hydrogen atoms fuse to convert into heavy nucleus of helium. A lot of energy is released in this nuclear reaction. Sun is the biggest source of energy. Energy of the sun reaching every year on earth is about 1.6×10^8 KWH (Kilo watt hour). Value of energy used by all the beings living on the earth is 7×10^{13} KWH per year. It is clear that every year energy received from the sun is 2000 times more than its annual consumption. Man has been using solar energy in making

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salt from the sea water, drying of clothes, heating water and in form of light. In the present technological era possibilities of more broad based utilisation of solar energy are bring explored. Solar energy is tapped for heat and electricity generation. Solar energy is used in solar cooker, solar heater and solar cells.

We know today, that the sun is simply our nearest star. Without it, life would not exist on our planet. We use the sun's energy every day in many different ways.

When we hang laundry outside to dry in the sun, we are using the sun's heat to do work drying our clothes.

Plants use the sun's light to make food. Animals eat plants for food, decaying plants hundreds of millions of years ago produced the coal, oil and natural gas that we use today. So, fossil fuels is actually sunlight stored millions and millions of years ago.

Indirectly, the sun or other stars are responsible for all our energy. Even nuclear energy comes from a star because the uranium atoms used in nuclear energy were created in the fury of a nova – a star exploding.

Solar energy is one the most resourceful sources of energy for the future. One of the reasons for this is that the total energy we receive each year from the sun is around 35,000 times the total energy used by man. However, about 1/3 of this energy is either absorbed by the outer atmosphere or reflected back into space (a process called albedo).

Solar power, or energy from the Sun, is a free, abundant, and nonpolluting source of energy. This vast, clean energy resource represents a viable alternative to the fossil fuels that currently pollute our air and water, threaten our public health, and contribute to global warming.

It is estimated that during a year India receives the energy equivalent to more than 5,000 trillion kWh. Under clear (cloudless) sky conditions, the daily average varies from 4 to 7 kWh/m^2.

The solar energy per unit time reaching unit area at outer edge of the earth's atmosphere exposed perpendicularly to the rays of the Sun at the average distance between the Sun and earth is known as the solar constant. It is estimated to be approximately 1.4 kJ per second per square metre or 1.4 kW/m^2.

Solar energy can be used to heat buildings and water and to produce electricity. However, the Sun does not always shine, and the process of collecting solar energy and storing it for use at night and on cloudy days is difficult and expensive.

Solar energy systems can be either passive or active. In a passive solar heating system, a building captures and stores the Sun's heat because of the way it is designed, the materials it is made of, or the heat-absorbing structures it possesses. An example of a passive system is a building with large windows facing south (that allow sunlight to enter) and with thick walls that store heat and release it at night.

Active solar energy systems use pumps or fans to circulate heat obtained by solar collectors. A solar collector is a device that absorbs the energy of the Sun and converts it to heat for heating buildings and water. Flat-plate collectors are mounted to the roofs of buildings and used for space heating. They are made of a heat-absorbing plate, such as aluminum or copper, covered by glass or plastic. Water or air circulating in the collector absorbs heat from the plate and is carried to a heat storage tank. The stored heat is circulated or blown over cold rooms using pumps or fans. A conventional heating system is used as a backup when solar heat is not available. Solar heating of water is accomplished using a collector, a hot water storage tank, and a pump to circulate water.

Solar power plants using energy from the Sun to produce steam for driving turbines to generate electricity could potentially replace fuel-driven power plants, producing energy without any environmental hazards.

SOLAR CELLS

Solar cell is such device which converts solar energy into electric energy. Solar cells are also known as photo voltaic cell (PV cell) because it works on the principle of photo-voltaic effect.

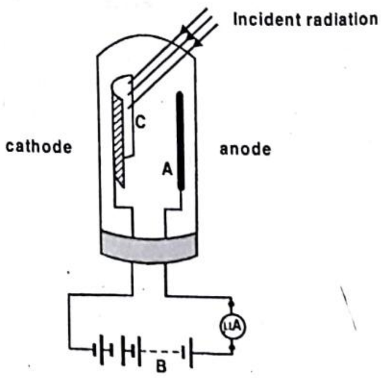

Fig : 8.12

Solar cells can be found on many small appliances, like calculators, and even on spacecraft.. They are made of silicon, a special type of melted sand. Silicon is abundant in nature but availability of the special grade silicon for making solar cells is limited.

When sunlight strikes the solar cell, electrons are knocked loose. They move toward the treated front surface. An electron imbalance is created between the front and back. When the two surfaces are joined by a connector, like a wire, a current of electricity occurs between the negative and positive sides.

These individual solar cells are arranged together in a PV module and the modules are grouped together in an array.

The electrical energy from solar cells can then be used directly. It can be used in a home for lights and appliances. It can be used in a business. Solar energy can be stored in batteries to light a roadside billboard at night. Or the energy can be stored in a battery for an emergency roadside cellular telephone when no telephone wires are around.

Some experimental cars also use PV cells. They convert sunlight directly into energy to power electric motors on the car.

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The principal advantages associated with solar cells are that they have no moving parts, require little maintenance and work quite satisfactorily without the use of any focussing device. Another advantage is that they can be set up in remote and inaccessible hamlets or very sparsely inhabited areas in which laying of a power transmission line may be expensive and not commercially viable. Artificial satellites and space probes like Mars orbiters use solar cells as the main source of energy. Radio or wireless transmission systems or TV relay stations in remote locations use solar cell panels.

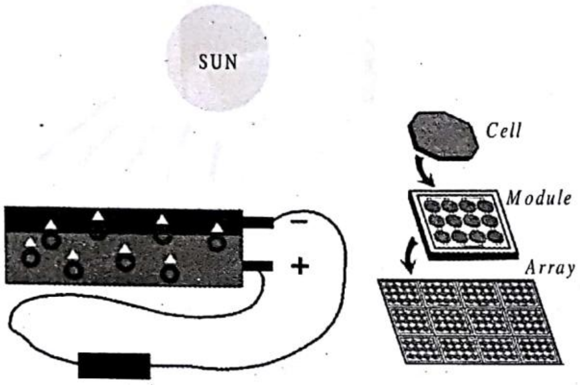

Fig : 8.13

Applications of photo electric cells :

1. Photocells are used in television cameras for telecasting scenes and photo telegraphy.
2. Photocells are used in reproduction of sound in motion pictures.
3. Photocells are used to switch on and off the street lights automatically.
4. These are used to obtain electric energy from sun light during space travel.
5. These are used to control temperature in furnaces and chemical reactions.
6. These are used in fire and burglar's alarm, to open and close the doors automatically and in counting devices.
7. These are used to compare illuminating power of two sources.
8. Photocells are used to detect opacity of solids, defects in materials, etc.

SOLAR COOKER

A solar cooker is a device that uses the energy in sunlight to generate sufficient temperatures to be able to cook food. Solar cookers can be used to perform most cooking tasks, such as baking cakes, roasting meat and vegetables, boiling soups, etc. The principle of using the sun to cook food is not a new concept. Swiss naturalist Horace de Saussure was known to have been experimenting with solar cookers as early as 1767. Three basic solar cooker designs exist:

- Parabolic Reflector • Box Cookers • Panel Cookers

Parabolic Reflectors

Two types of parabolic reflectors are available: trough and dish. Parabolic cookers focus the light from the sun at or along a focal axis, Dish cookers focus the sun onto one point and cook in a similar way to single hotplates whilst trough designs are similar to rotisseries and are best used for cooking long thin foods such as sausages.

Fig : 8.14

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Box Cookers

As higher temperatures are often required for the cooking of food than would normally be obtained with flat plate collectors used in water heating, box cookers usually have reflectors to increase the amount of radiation that enters the collector, as shown in Figure.

Fig : 8.15 A simple solar box cooker.

Panel Cookers

A relatively new style of solar cooker, a panel cooker consists of a number of flat reflection panels that direct light onto a container to be cooked.To retain the heat, the cooking dish is placed within a plastic bag or under a glass bowl.

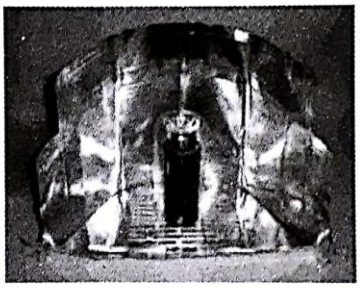

Fig : 8.16

ENERGY FROM THE SEA

Tidal Energy: (Extracts energy from the kinetic energy of the earth-moon-sun system)

Tide arise due to the gravitational pull of mainly the moon on the spinning earth. The tide moves a huge amount of water twice each day, and harnessing it could provide a great deal of energy. Although the energy supply is reliable and plentiful, converting it into useful electrical power is not easy.

Tidal energy has been used since about the 11th Century, when small dams were built along ocean estuaries and small streams. The tidal water behind these dams was used to turn water wheels to mill grains.

The simplest generation system for tidal plants involves a dam, known as a barrage, across an inlet. Sluice gates on the barrage allow the tidal basin to fill on the incoming high tides and to empty through the turbine system on the outgoing tide, also known as the ebb tide. There are two-way systems that generate electricity on both the incoming and outgoing tides.

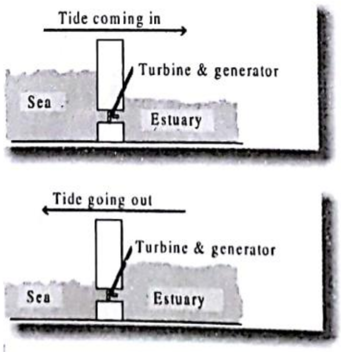

Fig : 8.17

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Tidal energy is renewable. The tides will continue to ebb and flow, and the energy is there for the taking.

A major drawback of tidal power stations is that they can only generate when the tide is flowing in or out - in other words, only for 10 hours each day. However, tides are totally predictable, so we can plan to have other power stations generating at those times when the tidal station is out of action.

Tidal fences can also harness the energy of tides. A tidal fence has vertical axis turbines mounted in a fence. All the water that passes is forced through the turbines. They can be used in areas such as channels between two landmasses. Tidal fences have less impact on the environment than tidal barrages although they can disrupt the movement of large marine animals. They are cheaper to install than tidal barrages too.

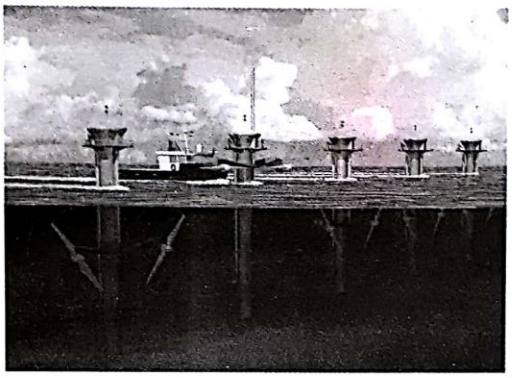

Fig : 8.18 Row of tidal current turbines

Advantages

- Once you've built it, tidal power is free.
- It needs no fuel.
- Not expensive to maintain.
- It produces no greenhouse gases or other waste.
- It produces electricity reliably.
- Tides are totally predictable.
- Offshore turbines and vertical-axis turbines are not ruinously expensive to build and do not have a large environmental impact.

Disadvantages

- A barrage across an estuary is very expensive to build, and affects a very wide area - the environment is cnanged for many miles upstream and downstream. Many birds rely on the tide uncovering the mud flats so that they can feed. There are few suitable sites for tidal barrages.
- Only provides power for around 10 hours each day, when the tide is actually moving in or out.

Why are there two high tides and two low tides per day?

Tides exist as the earth is affected by the non-uniform gravitational force from the moon. What is a non-uniform gravitational force? According to Newton's Law of universal gravitation, the gravitational force between two objects is inversely proportional to the square of the distance between them. That is, the shorter the distance, the greater the force, and the longer the distance, the weaker the force.

Please look at Figure. Point A experiences a greater lunar gravitational force than Point B (the earth's centre). Seawater is being attracted naturally towards the moon. A high tide is formed. Point C experiences a smaller lunar gravitational force than Point B, therefore the water level is higher here relative to Point B. Thus there are high tides at Point A and Point C, while the water levels at Point D and Point E are lower, that is, there are low tides.

During the rotation of the earth in one day, the location of the moon has no much change. Then a place on the earth will pass through two zones in which there are high tides. That is the reason why we see two high tides daily.

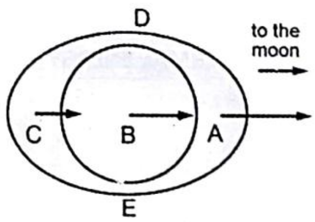

Fig : 8.19 The lunar gravitational force varies from place to place on the earth and this causes tides

WAVE ENERGY

Kinetic energy (movement) exists in the moving waves of the ocean. Waves are a powerful source of energy. That energy can be used to power a turbine.

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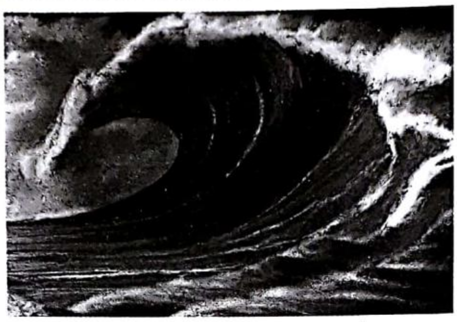

Fig : 8.20

There are several methods of getting energy from waves, but one of the most effective works like a swimming pool wave machine in reverse.

At a swimming pool, air is blown in and out of a chamber beside the pool, which makes the water outside bob up and down, causing waves. At a wave power station, the waves arriving cause the water in the chamber to rise and fall, which means that air is forced in and out of the hole in the top of the chamber.

We place a turbine in this hole, which is turned by the air rushing in and out. The turbine turns a generator

Most wave-energy systems are very small. But, they can be used to power a warning buoy or a small light house.

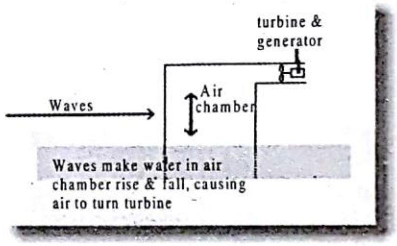

Fig : 8.21

Advantages

- The energy is free – no fuel needed, no waste produced.
- Not expensive to operate and maintain.
- Can produce a great deal of energy.

Disadvantages

- Depends on the waves – sometimes you'll get loads of energy, sometimes nothing.
- Needs a suitable site, where waves are consistently strong.
- Some designs are noisy.
- Must be able to withstand very rough weather.

Ocean Thermal Energy

The energy from the sun heats the surface water of the ocean. In tropical regions, the surface water can be 40 celsius or more degrees warmer than the deep water. This temperature difference can be used to produce electricity.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

The idea is not new. Using the temperature of water to make energy actually dates back to 1881 when a French Engineer by the name of Jacques D'Arsonval first thought of OTEC. The final ocean energy idea uses temperature differences in the ocean. If you ever went swimming in the ocean and dove deep below the surface, you would have noticed that the water gets colder the deeper you go. It's warmer on the surface because sunlight warms the water. But below the surface, the ocean gets very cold. That's why scuba divers wear wet suits when they dive down deep. Their wet suits trapped their body heat to keep them warm.

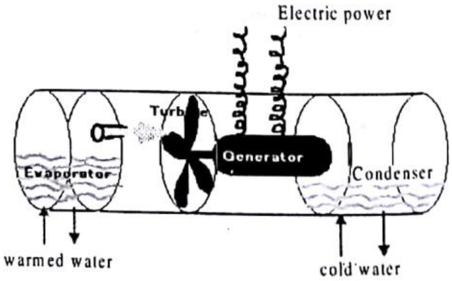

Fig : 8.22 OTEC system

OTEC generates electricity by using the temperature difference of 20°C (36°F) or more that exists between warm tropical waters at the sun-warmed surface, and colder waters drawn from depths of about 1000 m. To convert this thermal gradient into electrical energy, the warm water can be used to heat and vaporize a liquid (known as a working fluid). The working fluid develops pressure

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as it is caused to evaporate. This expanding vapor runs through a turbine generator and is then condensed back into a liquid by cold water brought up from depth, and the cycle is repeated. There are potentially three basic types of OTEC power plants: closed-cycle, open-cycle, and various blendings of the two. All three types can be built on land, on offshore platforms fixed to the seafloor, on floating platforms anchored to the seafloor, or on ships that move from place to place

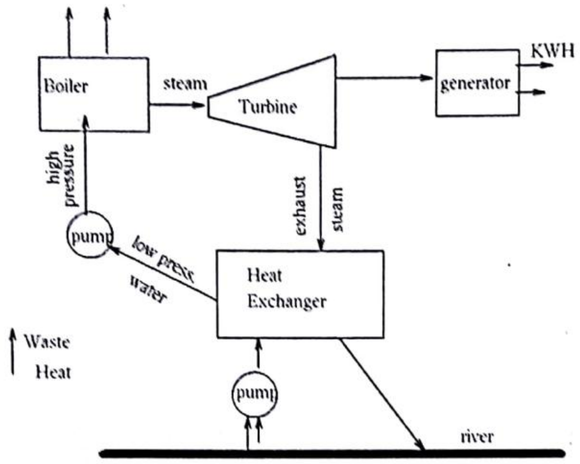


Fig : 8.23

GEOTHERMAL ENERGY

Energy present in the depth of the earth is called geothermal energy. As we move inside the earth from the earth surface the temperature increases with increasing depth. Temperature in the earth at a distance of 10 kilometres is about 120°C and it increases to 300°C at the depth of 320 kilometres. It is evident that temperature increases with depth. Melted liquid, megma is present in the depth of earth. It is surrounded by various layers of soil, sand and water. Whenever there is some passage, it comes in contact with water present between these layers and converts this water into the steam of sufficient pressure. This vapour pressure can be used for production of energy.

There is a huge possibility of the use of this energy in India because here there are 340 hot geological sites. In Manikarn and Kalleshwar the possibilities of the use of geothermal energy are explored. One of the main characteristics of the geothermal energy is that, it is pollution free.

Due to geological changes, molten rocks formed in the deeper hot regions of earth's crust are pushed upward and trapped in certain regions called 'hot spots'. When underground water comes in contact with the hot spot, steam is generated. Sometimes hot water from that region finds outlets at the surface. Such outlets are known as hot springs.

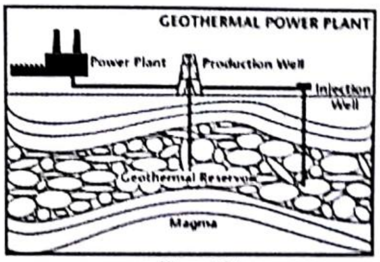


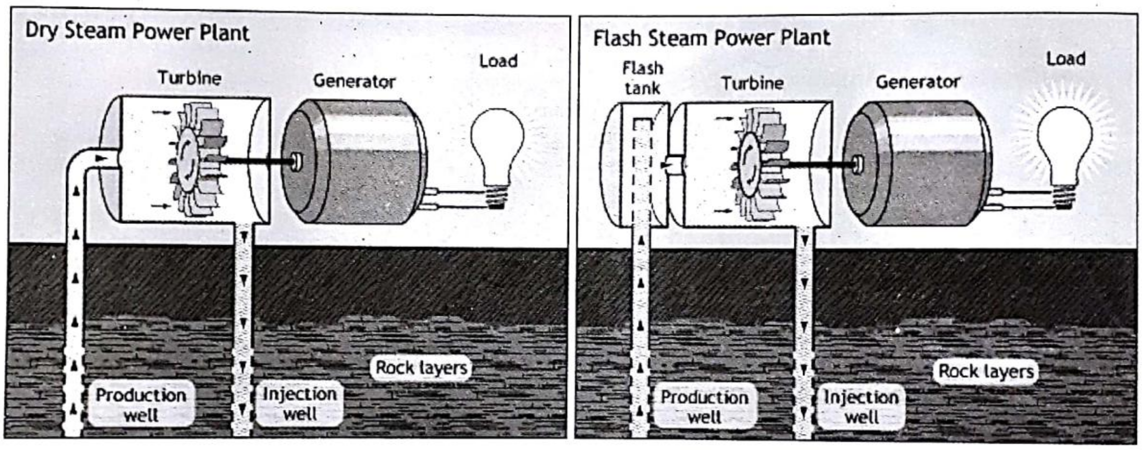
Fig : 8.24

Geothermal springs for power plants. The most common current way of capturing the energy from geothermal sources is to tap into naturally occurring "hydrothermal convection" systems where cooler water seeps into Earth's crust, is heated up, and then rises to the surface.

When heated water is forced to the surface, it is a relatively simple matter to capture that steam and use it to drive electric generators. Geothermal power plants drill their own holes into the rock to more effectively capture the steam.

There are three designs for geothermal power plants, all of which pull hot water and steam from the ground, use it, and then return it as warm water to prolong the life of the heat source. In the simplest design, the steam goes directly through the turbine, then into a condenser where the steam is condensed into water. In a second approach, very hot water is depressurized or "flashed" into steam which can then be used to drive the turbine.

In the third approach, called a binary system, the hot water is passed through a heat exchanger, where it heats a second liquid such as isobutane in a closed loop. The isobutane boils at a lower temperature than water, so it is more easily converted into steam to run the turbine. The three systems are shown in the diagrams below.



(a) Fig. 8.25 (b)

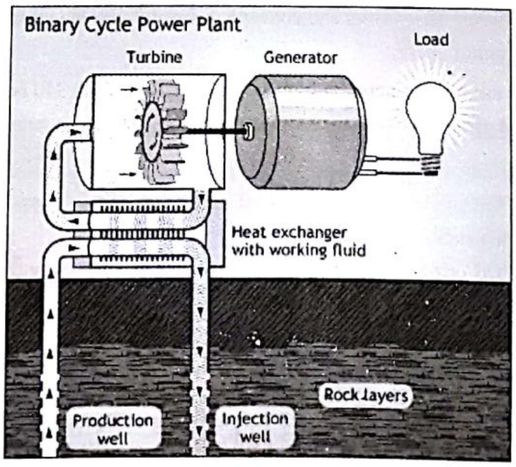


Fig : 8.27

The choice of which design to use is determined by the resource. If the water comes out of the well as steam, it can be used directly, as in the first design. If it is hot water of a high enough temperature, a flash system can be used, otherwise it must go through a heat exchanger. Since there are more hot water resources than pure steam or high-temperature water sources, there is more growth potential in the heat exchanger design.

Direct use of geothermal heat. Geothermal springs can also be used directly for heating purposes. Hot spring water is used to heat greenhouses, to dry out fish and de-ice roads, for improving oil recovery, and to heat fish farms and spas.

Hot dry rock. Geothermal heat occurs everywhere under the surface of the earth, but the conditions that make water circulate to the surface are found only in less than 10 percent of Earth's land area. An approach to capturing the heat in dry areas is known as "hot dry rock." The rocks are first broken up by pumping high-pressure water through them. Water is then pumped from the surface down through the broken hot rocks. After the water heats up, it is brought back to the surface through a second well and used to drive turbines for electricity or to provide heat.

The main problem with geothermal, of course, is lack of easily accessible surface sites

Direct use and heating applications have almost no negative impact on the environment.

Geothermal power plants do not burn fuel to generate electricity, so their emission levels are very low. They release about 1 to 3 percent of the carbon dioxide emissions of a fossil fuel plant. Geothermal plants use scrubber systems to clean the air of hydrogen sulfide that is naturally found in the steam and hot water. Geothermal plants emit 97 percent less acid rain - causing sulfur compounds than are emitted by fossil fuel plants. After the steam and water from a geothermal reservoir have been used, they are injected back into the earth.

In other places around the world, people used hot springs for rest and relaxation. The ancient Romans built elaborate buildings to enjoy hot baths, and the Japanese have enjoyed natural hot springs for centuries.

> ***In Iceland, virtually every building in the country is heated with hot spring water. In fact, Iceland gets more than 50 percent of its energy from geothermal sources. In Reykjavik, for example (population 115,000), hot water is piped in from 25 kilometers away, and residents use it for heating and for hot tap water.***

NUCLEAR ENERGY

Nuclear power is an alternative energy source that can be obtained from either the splitting of the nuclei of atoms (nuclear fission) or the combining of the nuclei of atoms (nuclear fusion). In either of these two reactions, great amounts of energy are released. Nuclear power plants use a device called a nuclear reactor in which uranium or plutonium atoms are split in controlled fission reactions. The heat energy released is captured and used to generate electricity. Nuclear energy from Uranium is not renewable. Once we've dug up all the Earth's uranium and used it, there isn't any more.

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1 EXERCISE

FIB Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. Many of the sources ultimately derive their energy from the............
2. Solar constant = ...
3. A device that utilises solar energy for cooking purposes is called a ....
4. A solar cell is a device which converts solar energy directly into ....
5. The energy possesses by wind is called ....
6. The flowing water possesses .... energy
7. Electricity generated from sea waves is ....
8. The internal heat of an earth is known as .... energy.
9. .... is the remaining part of the sugarcane from which juice has been extracted.
10. Bio-gas is a mixture of ...., carbon dioxide, ... and ....
11. When a complex material is heated strongly in the absence of air, then it decomposes to the simplest substance. This process is called ....
12. The material obtained from the bodies of plants and animals is called ....
13. The decomposition, which takes place in the absence of oxygen by anaerobic bacteria, is called ....
14. Coal gas is mixture of ...., ... and ....
15. Coal, petroleum and .... are the three important source of modern fuels.
16. The ultimate source of energy is ....

T/F True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Our energy requirements increase with our standard of living.
2. In order to fulfil our energy requirements, we try to improve the efficiency of energy usage and also try and exploit new sources of energy.
3. The main constituent of biogas is not methane.
4. Black colour is a very good absorber of heat and good reflector.
5. The use of geothermal energy cause pollution.
6. Deep drilling in the earth to obtain geothermal energy is very difficult.
7. Charcoal is a better fuel than wood and coal.
8. Biogas is a better fuel than animal dung-cakes.
9. The sun-rays fall on the equatorial region more intensively than any other part of the earth.
10. The calorific value of methane is less than that of butane.
11. Producer gas is obtained as one of the products of dry distillation of coal.
12. The sun is an ultimate source of fossil fuel.
13. Coal gas is an example of primary fuel.
14. Natural gas is renewable source of energy.
15. Gobar gas is a non-renewable source of energy.
16. Solar cookers make use of solar energy.
17. The sun is the ultimate source of energy.

MTF Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements in column I have to be matched with statements in column II.*

1.

Column I	Column II
A. Peat	p. liquid fuel
B. Alcohol	27% of carbon
C. Decay of biomass	r. Difference in temperature between warm surface waters and colder waters.
D. Rise and fall of water levels in oceans	s. biogas
E. OTEC	
F. Ultimate source of energy	t. tidal energy
	u. sun
G. Stored in food grains	v. wind
H. Moving air	w. bioenergy

VSAQ Very Short Answer Questions :

DIRECTIONS : *Give answer in one word or one sentence.*

1. Why CNG considered as environmental friendly fuel ?
2. Name two main combustible components of biogas.
3. Name the major constituent of natural gas.
4. State the energy transformation taking place when a boy is ridding a bicycle.
5. Name the main constituents of gas.
6. In what respect fuel oil is better than coal ?
7. What is baggage ? For what purpose can it be used ?

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8. How has the traditional use of wind and water energy been modified for our convenience?
9. What is geothermal energy?
10. Name two energy sources that you would consider to be renewable. Give reasons for your choices.
11. Give the names of two energy sources that you would consider to be exhaustible. Give reasons for your choices.
12. On what basis would you classify energy sources as (a) renewable and non-renewable? (b) exhaustible and inexhaustible?
    Are the options given in (a) and (b) the same?
13. Does wind possess kinetic for potential energy?
14. What is a turbine?
15. What do you mean by hydro energy?
16. What do you mean by tidal energy?
17. Why it is not possible to use the energy which is consumed?
18. What energy transformation takes place when we light a candle and drop a metal plate from a certain height?
19. What are fossil fuels?
20. What was the most common source of heat energy in ancient times?
21. Which fuel meets the growing demand of energy nowadays and the past?
22. Why most of the thermal power plants are set near coal or oil mines?
23. Why hydro power plants are associated with dams?
24. What is the composition of bio-gas and the matter rich in the slurry left behind in the bio-gas plant?
25. What energy transformation takes place in the solar cooker?
26. What is a solar cooker?
27. Which part of sunlight is used in heating a solar cooker?
28. What is a solar geyser?

SQA Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. List out the different power plants from which we get electrical energy?
2. What are the advantages and disadvantages of using energy from water?
3. What is biomass and write few examples of biomass?
4. How is charcoal formed and what are the advantages of using charcoal as a source of energy?
5. What is the major disadvantage of biomass and how can it be overcome ?
6. Write the different parts of a box type solar cooker
7. Explain the working of a solar cooker.
8. Which type of solar spectrum is trapped in the solar cooker?
9. To achieve higher temperature what is done in some solar cookers?
10. What is the cause for the tides on the ocean? (or) how are tides formed?
11. How wave energy is an indirect form of solar energy?
12. What are the limitations of harnessing wave energy?
13. What is OTEC?
14. What is the minimum requirement to operate the OTEC system?
15. List out the energies that are dependent and non-dependent of solar energy?
16. What are hot spots?
17. Why hot spots are important in harnessing Geothermal energy?
18. Name a few cites where geothermal energy is harnessed?
19. What are the limitations of harnessing Geothermal energy?
20. What are the advantages and disadvantages of Geothermal energy?
21. Write four functions performed by the sun's energy.

LAQ Long Answer Questions :

DIRECTIONS : *Give answer in four to five sentences.*

1. Write the working of a hydro power plant with a neat diagram?
2. Draw the schematic picture a solar cooker?
3. Electricity generated at hydroelectric power stations is considered to be another form of solar energy. Explain.
4. (a) Describe the steps involved in obtaining biogas and explain what is meant by anaerobic decomposition.
   (b) Which isotope of uranium can undergo fission readily?
5. Hydroenergy is an indirect source of solar energy. Justify this statement.
6. Explain what causes the wind to blow in equatorial regions. What is wind energy?
7. What is biogas? How can biogas be obtained? Why is the use of biogas obtained from cow dung advised in preference to burning of cow dung cakes?
8. Name three forms in which energy from ocean is made available for use. What are OTEC power plants ? How do they operate ?
9. Describe the construction of solar cooker. How does it cause rise in temperature to cook food?
10. (i) Distinguish between renewable and non-renewable sources of energy giving one example of each.
    (ii) Why is the use of wood as a fuel not advised although forests can be replenished?

2 EXERCISE

Multiple Choice Questions :

DIRECTIONS: *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Which of the following is a non-renewable source of energy?
   (a) Wood (b) Sun
   (c) Fossil fuels (d) Wind
2. Acid rain happens because
   (a) sun leads to heating of upper layer of atmosphere
   (b) burning of fossil fuels release oxides of carbon, nitrogen and sulphur in the atmosphere
   (c) electrical charges are produced due to friction amongest clouds
   (d) earth atmosphere contains acids
3. In a hydro power plant
   (a) Potential energy possessed by stored water is converted into electricity
   (b) Kinetic energy possessed by stored water is converted into potential energy
   (c) Electricity is extracted from water
   (d) Water is converted into steam to produce electricity
4. Which is the ultimate source of energy?
   (a) Water (b) Sun
   (c) Uranium (d) Fossil fuels
5. Ocean thermal energy is due to
   (a) energy strored by waves in the ocean
   (b) temperature difference at different levels in the ocean
   (c) pressure difference at different levels in the ocean
   (d) tides arising out in the ocean
6. Which part of the solar cooker is responsible for green house effect?
   (a) Coating with black colour inside the box
   (b) Mirror
   (c) Glass sheet
   (d) Outer cover of the solar cooker
7. The main constituent of biogas is
   (a) methane (b) carbon dioxide
   (c) hydrogen (d) hydrogen sulphide
8. The power generated in a windmill
   (a) is more in rainy season since damp air would mean more air mass hitting the blades
   (b) depends on the height of the tower
   (c) depends on wind velocity
   (d) can be increased by planting tall trees close to the tower
9. Choose the correct statement
   (a) Sun can be taken as an inexhaustible source of energy
   (b) There is infinite storage of fossil fuel inside the earth
   (c) Hydro and wind energy plants are non polluting sources of energy
   (d) Waste from a nuclear power plant can be easily disposed off
10. Choose the incorrect statement regarding wind power
   (a) its temperature increases
   (b) larger amount of potential energy is converted into kinetic energy
   (c) the electricity content of water increases with height
   (d) more water molecules dissociate into ions
11. Choose the incorrect statement regarding wind powerr
   (a) It is expected to harness wind power to minimum in open space
   (b) The potential energy content of wind blowing at high altitudes is the source of wind power
   (c) Wind hitting at the blades of a windmill causes them to rotate The rotation thus achieved can be utilised further
   (d) One possible method of utilising the energy of rotational motion of the blades of a windmill is to run the turbine of an electric generator
12. Most of the energy we use originally came from
   (a) the sun (b) the air
   (c) the soil (d) the oceans
13. Electrical energy can be produced from
   (a) mechanical energy (b) chemical energy
   (c) radiant energy (d) All of the above
14. Coal, petroleum, natural gas, and propane are fossil fuels. They are called fossil fuels because:
   (a) they are burned to release energy and they cause air pollution
   (b) they were formed from the buried remains of plants and tiny animals that lived hundred of millions of years ago
   (c) they are nonrenewable and will run out
   (d) they are mixed with fossils to provide energy
15. Gasoline is produced by refining which fossil fuel?
   (a) natural gas (b) coal
   (c) petroleum (d) propane
16. Propane is used instead of natural gas on many farms and in rural areas. Why is propane often used instead of natural gas?
   (a) it's safer (b) it's portable
   (c) it's cleaner (d) it's cheaper
17. What sector of the Indian economy consumes most of the nation's petroleum?
   (a) residential (b) commercial
   (c) industrial (d) transportation

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18. Natural gas is transported mainly by
(a) pipelines (b) trucks
(c) barges (d) all three equally

19. Global warming focuses on an increase in the level of which gas in the atmosphere?
(a) ozone (b) sulfur dioxide
(c) carbon dioxide (d) nitrous oxide

20. Solar, biomass, geothermal, wind, and hydropower energy are all renewable sources of energy. They are called renewable because they
(a) are clean and free to use
(b) can be converted directly into heat and electricity
(c) can be replenished by nature in a short period of time
(d) do not produce air pollution

21. Today, which renewable energy source provides the India with the most energy?
(a) wind (b) solar
(c) geothermal (d) hydropower

22. How much of the energy in burning coal reaches the consumer as electricity
(a) 1/3 (one-third) (b) 1/2 (one-half)
(c) 3/4 (three-quarters) (d) 9/10 (nine-tenths)

23. Which form of energy is contained in wind energy
(a) Kinetic energy (b) Potential energy
(c) Electric energy (d) Thermal energy

24. In biogas, which gas is present in maximum amount
(a) Carbon dioxide (b) Methane
(c) Hydrogen (d) Oxygen

25. Which one of the following is not a source of non-convential energy
(a) Coal (b) Solar energy
(c) Wind energy (d) Biogas

26. White energy is freely available in ample amount of
(a) Sunlight (b) Water gas
(c) Hydrogen (d) Wind energy

27. Gobar gas is
(a) foul smelling gas
(b) sweet smelling gas
(c) having high caloric value
(d) useless

28. Biogas is produced from biomatter by
(a) anaerobic fermentation
(b) distructing distillation
(c) fractional distillation
(d) mixing petrol in biomatter

29. L.P.G. is mostly liquified
(a) hydrogen (b) oxygen
(c) butane (d) methane

30. A solar water heater cannot be used to get hot water on
(a) a sunny day (b) a cloudy day
(c) a hot day (d) a windy day

31. Which of the following is not an example of a biomass energy source
(a) wood (b) gobargas
(c) nuclear energy (d) coal

32. Most of the sources of energy we use represent stored solar energy. Which of the following is not ultimately derived from the Sun's energy?
(a) geothermal energy (b) wind energy
(c) nuclear energy (d) bio-mass.

33. An example of secondary fuel is
(a) coal (b) water gas
(c) natural gas (d) petroleum

34. Which of the following is an example of fossil fuel
(a) coal gas (b) coke
(c) natural gas (d) producer gas

35. Most of the fuels are
(a) carbon compounds with sulphur
(b) nitrogen compounds with carbon
(c) carbon compounds with hydrogen
(d) none of these

36. Producer gas is a mixture of
(a) carbon monoxide and nitrogen gas
(b) carbon monoxide and hydrogen gas
(c) carbon monoxide and water vapour
(d) carbon monoxide and nitrous oxide

37. The fractional distillation of coal tar yields
(a) carbon disulphide (b) carbon tetrachloride
(c) kerosene oil (d) benzene

38. Which of the following is not used as a rocket fuel?
(a) synthetic rubber (b) liquid hydrogen
(c) paraffin (d) liquid nitrogen

39. The fraction of the sun's energy received on earth is about
(a) 12% (b) 26%
(c) 38% (d) 47%

40. Which of the following source of energy is different from others?
(a) coal (b) lignite
(c) petroleum (d) plants

41. Which of the following source of energy is different from others
(a) bitumen (b) anthracite
(C) coke (d) gobar gas

42. Choose the only renewable source of energy
(a) coal (b) uranium
(c) natural gas (d) geothermal power

43. Which of the following is a false statement?
(a) To overcome the energy crisis the use of solar cooker must be increased.
(b) To overcome the energy crisis more amount of non-renewable sources of energy must be used.
(c) The re-usage of waste material as a source of energy can be done to overcome the energy crisis.
(d) To overcome the energy crisis water has to be saved.

44. The main constituent of LPG is butane. Then
(A) butane can be liquefied easily under high pressure.
(B) butane is liquefied by chemically reacting with ethane and propane.
(a) Only A is true
(b) Only B is true
(c) Both A and B are true
(d) Both A and B are false

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45. Which element contained in a fuel contributes to its high calorific value?
(a) Carbon (b) Hydrogen
(c) Oxygen (d) Nitrogen

46. Combustion, the process of burning a fuel, is
(A) an oxidation and an exothermic reaction.
(B) a reduction and an endothermic reaction.
(a) Only A is true
(b) Only B is true
(c) Both A and B are true
(d) Both A and B are false

47. .... is used as a fuel in space ships.
(a) Hydrogen (b) Alcohol
(c) Petrol (d) Diesel

48. In solar water heater, a copper pipe with its outer surface painted in black is fixed in the form of a coil in box.
(a) The only purpose of bending copper pipe is to increase the capacity of water storage.
(b) Bending copper pipe as a coil helps to increase the surface area for heating.
(c) Both (1) and (2) are true
(d) Both (1) and (2) are false

49. In the extraction of some metals from their ores, coke can be used as a /an
(a) oxidizing agent (b) reducing agent
(c) catalyst (d) flux

50. Find the false statement from the following statements given below:
(a) Geothermal power plants cannot operate round the clock.
(b) The initial cost in setting up this plant will be high.
(c) This type of source is free and renewable.
(d) Operating cost involved in a geothermal plant is less.

51. are used to produce energy in OTEC.
(a) Tidal energy
(b) Temperature difference between the different layers of water in ocean
(c) Ocean waves
(d) None of the above

52. The curde oil extracted from the earth is separated into its constituents by a process called
(a) disintegration distillation
(b) compound idstillation
(c) destructive distillation
(d) fractional distillation

53. Among the following the sources of energy for which source sun is not a chief source of energy is
(a) Hydroelectric power plant
(b) Ocean thermal energy conversion (OTEC)
(c) Tidal energy
(d) Biomass

54. What is the value of solar constant if the energy received by 12 m^2 area in 2 minutes is 2016 kJ?
(a) 1.4×10^2 J s^{-1} m^{-2} (b) 1400 J s^{-1} m^{-2}
(c) 84 kJ s^{-1} m^{-2} (d) 84 J s^{-1} m^{-2}

55. A good fuel should
(a) be safe to store and transport
(b) be able to provide desired quantity of energy at a steady rate over a long period of time
(c) have low content of non-combustibles and no combustion products that are poisonous or environmental pollutants
(d) All the above

56. Find the false statement from the following statements given below:
(a) Geothermal power plants cannot operate round the clock
(b) The initial cost in setting up this plant will be high
(c) This type of source is free and renewable
(d) Operating cost involved in a geothermal plant is less

MTOC More than One Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. Which of the following are ture statements?
(a) To overcome the energy crisis the use of solar cooker must be increased.
(b) To overcome the energy crisis more amount of non-renewable sources of energy must be used.
(c) The re-usage of waste material as a source of energy can be done to overcome the energy crisis.
(d) To overcome the energy crisis water has to be saved.

2. Find the true statements from the following statements given below:
(a) Geothermal power plants cannot operate round the clock.
(b) The initial cost in setting up this plant will be high.
(c) This type of source is free and renewable.
(d) Operating cost involved in a geothermal plant is less.

3. Which of the following are renewable sources of energy?
(a) Wood (b) Sun
(c) Fossil fuels (d) Wind

4. Which are not ultimate sources of energy?
(a) Water (b) Sun
(c) Uranium (d) Fossil fuels

5. Ocean thermal energy is not due to
(a) energy strored by waves in the ocean
(b) temperature difference at different levels in the ocean
(c) pressure difference at different levels in the ocean
(d) tides arising out in the ocean

6. Which parts of the solar cooker are not responsible for green house effect?
(a) Coating with black colour inside the box
(b) Mirror
(c) Glass sheet
(d) Outer cover of the solar cooker

7. The main constituents of biogas are not
   (a) methane (b) carbon dioxide
   (c) hydrogen (d) hydrogen sulphide
8. Choose the incorrect statements
   (a) Sun can be taken as an inexhaustible source of energy
   (b) There is infinite storage of fossil fuel inside the earth
   (c) Hydro and wind energy plants are non polluting sources of energy
   (d) Waste from a nuclear power plant can be easily disposed off
9. Choose the correct statements regarding wind powerr
   (a) It is expected to harness wind power to minimum in open space
   (b) The potential energy content of wind blowing at high altitudes is the source of wind power
   (c) Wind hitting at the blades of a windmill causes them to rottate The rotation thus achieved can be utilised further
   (d) One possible method of utilising the energy of rotational motion of the blades of a windmill is to run the turbine of an electric generator
10. Choose the correct statements?
    (a) We are encouraged to plant more trees so as to ensure clean environment and also provide bio-mass fuel
    (b) Gobar-gas is produced when crops, vegetable wastes, etc., decompose in the absence of oxygen
    (c) The main ingredient of bio-gas is ethane and it gives a lot of smoke and also produces a lot of residual ash
    (d) Bio-mass is a renewable source of energy

FIP Fill in the Passage :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

I.

organic	decomposed	composed	creating	decomping	bacteria	oxygen	releasing

Bio gas is made from ....1.......... waste matter after it is ....2........... The decomposition breaks down the organic matter, ...3......... various gases. The main gases released are methane, carbon dioxide, hydrogen and hydrogen sulphide. Bacteria carry out the decomposition or fermentation. The conditions for ....4.......... bio gas has to be anaerobic that is without any air and in the presence of water. The organic waste matter is generally animal or cattle dung, plant wastes, etc. These waste products contain carbohydrates, proteins and fat material that are broken down by ....5.......... The waste matter is soaked in water to give the bacteria a proper medium to grow. Absence of air or oxygen is important for decomposition because bacteria then take ....6.......... from the waste material itself and in the process break them down.

II.

produce	reduce	carbon dioxide (CO_2)	
contribute	dependence	independence	gasoline

Using biomass can help ....1.......... global warming compared to a fossil fuel-powered plant. Plants use and store .....,..2.......... when they grow. CO_2 stored in the plant is released when the plant material is burned or decays. By replanting the crops, the new plants can use the CO_2 produced by the burned plants. So using biomass and replanting helps close the carbon dioxide cycle. However, if the crops are not replanted, then biomass can emit carbon dioxide that will ....3.......... toward global warming.
So, the use of biomass can be environmentally friendly because the biomass is reduced, recycled and then reused. Today, new ways of using biomass are still being discovered. One way is to ....4.......... ethanol, a liquid alcohol fuel. Ethanol can be used in special types of cars that are made for using alcohol ....5..........can also be combined with gasoline. This reduces our ....6.......... on oil a non-renewable fossil fuel.

II.

convert	**wind energy**	**wind**	**blades**	**mechanical**
thermal	**rotate**	**pressure**		**volume**

Moving are is called ....1.......... . Sun's energy (solar energy) is one of the main factors responsible for the motion of air in the atmosphere. Windmills are devices that convert ....2.......... into mechanical or electrical energy. They were used for grinding grains in many parts of the world, until a 100 years ago. Modern windmills are designed to ....3.......... wind energy into mechanical or electrical energy, in a large scale. A windmill essentially consists of a structure similar to that of a large electric fan that is erected at some height on a rigid support.
The principle of a windmill is that the ....4.......... of a windmill are designed to create a ....5..........difference between its different regions when wind strikes them. This pressure difference produces a turning effect to make the blades ....6..........
In a water-lifting pump, the rotational motion of windmill is utilised to do ....7.......... work and draw underground water to the surface of the earth.

IV.

70.8%	biggest	heat capacity	energy

Oceans covers about ....1......... of the earth's surface and are the ....2.......... source of water on the earth. Because of the large mass of water in oceans and high ......3....... of water, oceans at as store house of ......4.........

V.

Light	heat	electrical	gasoline
contains	capacity	mechanical	thermal
chemical	electrical	radial (light)	nuclear

Energy causes things to happen around us. Look out the window. During the day, the sun gives out ....1......... and .....2..... energy. At night, street lamps use .....3...... energy to

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light our way. When a car drives by, it is being powered by ......4....., a type of stored energy. The food we eat .....5...... energy. We use that energy to work and play.

Energy is the .....6...... to work. It may exist in many forms. Energy can be found in ......7..... , ...8....., ...9......, ...10........, ...11...... (light) and ......12..... forms

Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.

(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.

(c) If **Assertion** is **correct** but **Reason** is **incorrect**.

(d) If **Assertion** is **incorrect** but **Reason** is **correct**.

1. **Assertion :** Nuclear forces are independent of charges.
   Reason : Nuclear force is not a central force.
2. **Assertion :** The strength of photoelectric current depends upon the intensity of incident radiation.
   Reason : A photon of energy E (= hv) possesses a mass equal to E/c^2 and momentum equal to E/c.
3. **Assertion :** Binding energy (or mass defect) of hydrogen nucleus is zero.
   Reason : Hydrogen nucleus contain only one nucleon.
4. **Assertion :** U^{235} nucleus, by absorbing a slow neutron undergoes nuclear fission with the evolution of a significant quantity of heat
   Reason : During nuclear fission a part of the original mass of U^{235} is lost and gets converted into heat.
5. **Assertion :** The rest mass energy of a nucleus is smaller than the rest mass energy of its constituent nucleons in free state.
   Reason : Nucleons are bound together in a nucleus.
6. **Assertion :** In a decay process of a nucleus, the mass of products is less than that of the parent.
   Reason : The rest mass energy of the products must be less than that of the parents.
7. **Assertion :** In street light circuits, photo-cells are used to switch on and off the lights automatically at dusk and dawn.
   Reason : A photocell can convert a change in intensity of illumination into a change in photocurrent that can be used to control lighting system.

HOTS Subjective Questions :

DIRECTIONS : *Answer the following questions.*

1. Why is geothermal energy better than wind energy for power generation?
2. "A burning match stick can ignite a piece of paper or an incense stick but cannot burn a wooden block". Given reasons.
3. The sun is the ultimate source of energy on earth. Is the given statement true with respect to fossil fuels?
4. Suppose a green tree absorbs, on an average, 10^8J of solar energy per day, incident on it and the tree could convert 1% of the solar energy incident on it to produce wood, how many days would it take to produce 50 kg of wood? (The calorific value of wood is 15 kJ g^{-1}).
5. Water that falls from a waterfall is used to generate electricity. If the height of water fall is 100 m and $10^2 m^3$ of water falls every minute, then find the hydel energy in MW h generated in one day. Assume that 60% of the energy of the flowing water is converted into electricity. (Take density of water as 1000 kg m^{-3}).
6. Among methane (CH_4) and methyl alcohol (CH_3OH) which is a better fuel and why?
7. 10 kg of water at 30°C is heated to its boiling point on a stove that uses LPG as fuel. If the efficiency of the stove is 70%, then find the mass of the fuel that is consumed. Take the calorific value of LPG (Butane) as 55,000 kJ kg^{-1}.
8. Find the electrical power generated in 1s by a wind mill that is erected in a location when air flows with an average speed of 54 km h^{-1}. Assume that the moving air is completely stopped by the blades of the wind turbine of area 10 m^2, over which air flows normally and the energy conversion from wind energy to electrical energy is only 50%. (Take density of air = 0.3 kg m^{-3})
9. What is the source of energy in artificial satellites? Why is this source of energy not used for meeting all our domestic electricity needs?
10. Why is it not feasible to produce hydroelectricity by spending energy in lifting a huge amount of water? Explain.
11. Explain why :
    (i) It is difficult to burn a piece of wood fresh from a tree.
    (ii) Pouring dry sand over the fire extinguishes it.
    (iii) It is difficult to use hydrogen as a source of energy.
    (iv) Charcoal is considered a better fuel than wood.
12. Name the major fuel component of biogas. What are its other combustible components ? What is the use for the residual slurry and why ?
13. What is the main basic cause for wind to blow ? Name a part of India where wind energy is commercially harnessed. Compare wind power and power of water flow in respect of generating mechanical and electrical energies. What is the hindrance in developing them ?
14. What are the qualities of an ideal source of energy ?
15. What are the environmental consequences of the increasing demand for energy ?
    What steps would you suggest to reduce energy consumption?

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SOLUTIONS

Brief Explanations of Selected Questions

Exercise 1

FILL IN THE BLANKS :

1. Sun
2. 1.4 kW/m^2
3. solar cooker.
4. electricity.
5. wind energy
6. kinetic
7. tidal energy
8. geothermal
9. Bagasse
10. methane, hydrogen, hydrogen sulphide
11. destructive distillation.
12. biomass
13. anaerobic degradation
14. H_2, CH_4 and CO
15. natural gas
16. sun

TRUE / FALSE

1. True	2. True	3. False
4. False	5. False	6. True
7. True	8. True	9. True
10. False	11. False	12. True
13. False	14. False	15. False
16. True	17. True	

MATCH THE FOLLOWING :

1. (A) → q; (B) → p; (C) → s; (D) → t; (E) → r; (F) → u; (g) → w; (H) → v

VERY SHORT ANSWER QUESTIONS :

1. CNG gas create less pollution.
2. (i) Methane (ii) Hydrogen.
3. The major constituent of natural gas is methane.
4. Muscular energy to Mechanical energy.
5. Methane is the main constituent of Biogas.
6. (i) Fuel oil has higher calorific value than coal.
   (ii) Fuel oil does not leave ash or residue.
7. Baggage is peels of sugar cane after taking out juice from it. It is used as a fuel.
8. The traditional use of wind has been modified by using windmills and that of water by constructing hydroelectric power plants.
9. The energy extracted from hot water springs on the earth is called geothermal energy.
10. (i) wind energy (ii) solar energy
    These sources of energy can be used again and again endlessly. They will never get exhausted.
11. (i) Fossil fuels (ii) Nuclear fuels
    Fossil fuels are present in a limited amount in the earth. Once exhausted, they will not be available to us again. The nuclear material which can be conveniently extracted from the earth are limited and hence they will get exhausted one day.
12. We would classify energy sources as (a) renewable and non-renewable.
    Renewable sources of energy are inexhaustible whereas non-renewable sources of energy are exhaustible. Thus, the options in (a) and (b) are the same.
13. Kinetic energy
14. It is a machine for converting the kinetic energy of the fluid (flowing water or gas) into mechanical energy.
15. The energy of water is called hydro energy.
16. The enormous movement of water between the high tides and low tides provides a source of energy, which is called tidal energy.
26. It is a device that cooks food by absorbing solar radiations.
27. Infra-red radiations.
28. It is a device used to supply hot water using sunlight.

LONG ANSWER QUESTIONS :

3. The energy of water (or hydro-energy) is in fact an indirect source of solar energy because it is the solar energy which is responsible for water cycle. The heat of solar energy evaporates water from ocean and the surface of the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth in the form of rain and snow. The rain water and the water formed by melting of snow then flows rapidly in the rivers and provides us with hydro energy.
4. (a) Anaerobic decomposition : The process in which the complex compound of cow dung slurry decomposes or breaks down in the absence of oxygen by anaerobic micro-organisms called anaerobic bacteria is known as anaerobic decomposition.
   It generates gases like methane (75%), carbon dioxide, hydrogen and hydrogen sulphide.
   Steps involved in obtaining biogas :
   (i) Slurry is made by mixing of animal dung with an equal amount of water.
   (ii) Slurry is passed through an inlet chamber of an underground digester tank.

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(iii) In digester tank, slurry is decomposed by anaerobic bacteria in about 50-60 days to produce biogas.

(iv)The biogas collected in domes built over the digester tank and has a gas outlet with value.

(v) The pressure exerted by the biogas on the slurry forces the spent slurry to the overflow tank via outlet chamber.

(vi) The spent slurry is periodically removed and used as a good manure.

(vii) The whole process is repeated again for regular supply of biogas.

(b) $^{235}_{92}U$ can undergo fission readily.

5. The energy of water (or hydro-energy) is in fact an indirect source of solar energy because it is the solar energy which is responsible for water cycle. The heat of solar energy evaporates water from ocean and the surface of the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth. The water vapours rise high in the atmosphere, get cooled and fall back to the earth in the form of rain and snow. The rain water and the water formed by melting of snow then flows rapidly in the rivers and provides us with hydro energy.

6. Solar energy is responsible for wind to blow. The intensity of sun-rays is much more stronger near the equator of the earth than in the polar region. Due to more intense heat, the air near the surface of the earth in equatorial regions become quite hot. The hot air being lighter rises upward and cooler air from the polar region of earth starts flowing which causes wind to blow from the high pressure to low pressure region. So wind blows to equatorial regions. The energy possessed by this wind is called wind energy.

7. Biogas. The gas produced by the decay of biomass in the presence of water by anaerobic micro-organisms in the absence of oxygen is called biogas. Biogas can be obtained by using fixed dome type biogas plant.

The burning of cow-dung cakes is not advisable because of the following reasons :

(i) It produces a lot of ash as residue.

(ii) It produces a lot of smoke causes air pollution as well as creates health hazards.

(iii) It has low heat efficient fuel.

(iv) It destroys the useful manure.

Whereas during the production of biogas only organic matter is decomposed by anaerobic bacteria and convert into biogas. So use of biogas obtained from cow dung advised in preference gives (i) a clean fuel, free from pollution and (ii) spent slurry can be used as a manure.

8. Three forms of oceanic energy are

(a) Sea wave energy

(b) Tidal energy

(c) Ocean thermal energy.

OTEC power plant. The plants which are used to harness ocean thermal energy is called OTEC power plant.

Working of OTEC power plant. A temperature difference between warm surface water heated by sun and colder water at deeper level upto 1000 m is 20°C or more is required to operate OTEC plant.

In the OTEC system, the warm surface water is used to boil a liquid like ammonia. The vapour of liquid is then used to rotate the turbine of a generator. The cold water from the deeper level is used to convert the ammonia vapour again into liquid.

9. Construction. It consists of an insulated metal box which is painted all black from inside. There is thick glass sheet as a cover over the box and a plane mirror reflector attached to the box.

Cooking of food. The food to be cooked is placed in a metal container kept in the box and covered with glass sheet. When solar energy falls on reflector, the reflector sends them to the top of solar cooker in the form of strong beam of sunlight which is absorbed by the black surface in the box. The infra-red rays cause heating effect which raises the temperature to 100°C–140°C which cooks the food.

10. (i) Renewable sources of energy are those that can be used without depleting their reserves and do not get exhausted e.g., solar energy, wind energy, hydro energy, etc.

Non-renewable sources of energy are those which cannot be replenished and exhausted with the passage of time. e.g., : coal, petroleum and natural gas.

(ii) Wood is not advisable used as a fuel, although forests can be replenished, due to the following reasons :

(a) Burning of wood causes pollution.

(b) The left-over residue after combustion have a disposed off problem.

(c) Smoke produced by burning of wood causes health hazard.

(d) Wood is a less heat generating fuel.

(e) Trees are essential for our life as they absorb CO_2 and give out O_2.

Exercise 2

MULTIPLE CHOICE QUESTIONS :

1.	(c)	2.	(b)	3.	(a)	4.	(b)	5.	(b)
6.	(c)	7.	(a)	8.	(c)	9.	(a)	10.	(b)
11.	(b)	12.	(a)	13.	(d)	14.	(b)	15.	(c)
16.	(b)	17.	(d)	18.	(a)	19.	(c)	20.	(c)
21.	(d)	22.	(a)	23.	(a)	24.	(b)	25.	(a)
26.	(a)	27.	(c)	28.	(a)	29.	(c)	30.	(b)
31.	(c)	32.	(c)	33.	(b)	34.	(c)	35.	(c)
36.	(a)	37.	(d)	38.	(d)	39.	(d)	40.	(d)
41.	(d)	42.	(b)	43.	(a)	44.	(b)	45.	(a)
46.	(a)	47.	(b)	48.	(b)	49.	(a)	50.	(b)
51.	(d)	52.	(c)	53.	(b)	54.	(d)	55.	(a)
56.	(b)								

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More Than One Correct :

1. (a, c, d) 2. (b, c, d) 3. (a,b,d) 4. (a,b,d)
5. (a,c,d) 6. (a,b,d) 7. (b,c,d) 8. (b,c,d)
9. (a,c,d) 10. (a,b,d)

Fill in the Passage :

I. 1.organic 2. decomposed 3. releasing 4.creating 5. bacteria 6. oxygen

II. 1. reduce 2. carbon dioxide (CO_2) 3. contribute 4. produce 5. gasoline 6.dependence

III. 1. wind 2. wind energy 3. convert 4. blades 5. pressure 6. rotate 7. mechanical

IV. 70.8%, biggest, heat capacity, energy.

V. Light, heat ,electrical, gasoline, contains, capacity mechanical, thermal, chemical, electrical, radial (light) ,nuclear

Assertion & Reason :

1. (b) 2. (b) 3. (a) 4. (a) 5. (a)
6. (a) 7. (a)

Hots Subjective Questions :

4. (i) Find q (i.e.,) 1% of 10^8J. This is the solar energy that is converted to wood in one day.

Find the amount of heat energy liberated on burning 50 kg of wood by using the formula,

Q = mS .... (1) where S is the calorific value of wood.

Then, find the number of days required to produce 50 kg of wood by using formula,

Q = nq = mS ....(2)

(ii) 750 days

5. (i) Find the amount of water (m) flows in one day.

Let the volume of water that flows in every minute = V.

(ii) Density of water (d) = $\frac{m}{V}$

(iii) One day = 24 × 60 minutes

(iv) Mass of the water that flows in one day is m = Vd × (60 × 24)

(v) Potential energy, PE = mgh

(vi) The energy of the flowing water in one day is = mgh

(vii) 60% of the (mgh) is used to generate electricity

(viii) 24 × 10^3 kW h or 24 MW h

6. (i) Which one of the given fuelsmethane and methyl alcohol, has got more percentage of hydrogen?

Among the given molecules, which has got simpler molecular structure?

(ii) CH_4 is a better fuel.

7. (i) Find the amount of heat (Q) required to boil given water by using Q = ms (Δt).

(ii) The above value of Q is only 70% of the amount of heat liberated by combustion of fuel (Q^1)

(iii) Then the mass of the fuel combusted is, $m_{fuel} = \frac{Q^1}{S}$

(iv) 76 g

8. (i) The volume of air that makes blades to rotate = V = ℓ × area of the blade

(ii) Velocity (v) = $\frac{\ell}{t}$

(iii) Mass of the air = m = volume × density of air

(iv) Kinetic energy (KE) of air = $\frac{1}{2}mv^2$

(v) 50% of kinetic energy of air is converted into electrical energy (EE)

(vi) The power of electrical generation is, $P = \frac{EE}{1s}$

(vii) 2.53 kW

11. (i) It is because a piece of fresh wood is not dry and therefore it is to be heated at high temperature before it catches fire, that is why it is difficult to burn.

(ii) It cuts off the supply of air (oxygen) which is required for combustion to take place.

(iii) Hydrogen is highly combustible and burns with an explosion, therefore, it is difficult to store and transport.

(iv) Charcoal, has higher calorific value than wood and produces less smoke than wood.

12. Major fuel component of biogas–Methane. Other combustile component of biogas–Hydrogen, Hydrogen sulphide, Carbon dioxide.

Use of residue slurry. Left-over slurry from the biogas plant is used as a manure because it is rich in nitrogen and phosphorus compounds and can be used in place of nitrogeneous and phosphorus fertilizers.

13. Cause of wind to blow. Unequal heating of the different land mass and water bodies such as river, lake, ocean etc. by solar radiations creates a different pressure regions. The flow of air from higher pressure region i.e., polar region towards the lower pressure region i.e., equatorial region, constitutes wind.

It is Kanya Kumari in Tamil Nadu where wind energy is commercially harnessed.

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Wind power potential. From the wind power India generates only 2000 MW whereas India has the potential to generate 45000 MW of electrical power from wind energy.

Hydro power potential. It is estimated that India can generate about 4×10^{11} kWh of electricity when its hydro power potential is fully exploited. At present, India can exploit only 11% of its potential capacity.

Drawbacks of wind power plant.

(i) Wind is not available at all the places all the time.

(ii) Establishment of wind energy requires large area and huge structure of windmill which increase the cost.

Drawbacks of hydro power plant.

(i) The imbalance in ecosystem over a long period of time.

(ii) Conversion efficiency of water energy into electrical energy is very low.

14. (i) An ideal fuel is that which gives us more heat per unit mass.

(ii) An ideal fuel is that which does not pollute air on burning by giving out smoke or harmful gases.

(iii) It should be cheap and easily available.

(iv) It should be easy to handle, safe to transport.

15. (i) More pollution levels.

(ii) Quicker depletion of conventional sources.

Overcoming Energy Crisis. Energy crisis can be overcome by :

(i) Judicious use of the available energy

(ii) Promoting renewable energy sources

(iii) Promoting efficient conversion mechanism and

(iv) Accelerate the pace of development of technologies required for harnessing new sources.

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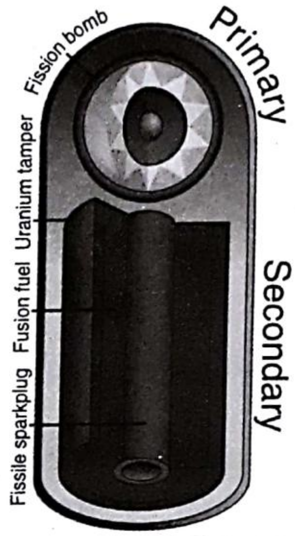
chapter 9



MODERN PHYSICS

Introduction

All matters are composed of what is called 'atom'. Atom is composed of fundamental particles and it has a nucleus in which its mass is concentrated.

The story of how atom was discovered is very long. But the brief story is that first of all Thomson provided something acceptable in scientific community about the atom. After him, Rutherford presented the modified and almost acceptable atomic model but it had also some discrepencies which was removed by Neils Bohr when he presented the most updated form of the atomic model in 1913.

This chapter provides us the structure of atom and its different features. The chapter also gives a glimpse of the nucleus and different phenomena occuring in it like radioactivity, fission, fusion etc.

You will also study the applications of these nuclear phenomena such as in atom bomb, hydrogen bomb, nuclear reactor and so on.

ATOMIC MODEL THOMSON ATOMIC MODEL

This model suggests an atom to be a tiny sphere of radius $\approx 10^{-10}$ m, containing the positive charge. The atom is electrically neutral. It contains an equal negative charge in the form of electrons, which are embedded randomly in this sphere, like seeds in a watermelon.

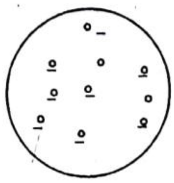


Fig 9.1 Thomson's atomic model

This model failed to explain (i) large scattering angle of α-particle (ii) origin of spectral lines observed in the spectrum of hydrogen atom.

RUTHERFORD'S ATOMIC MODEL

(a) Atom is sphere of diameter about 10–10 m and central part called nucleus contains + ve charge and most of the masses of atom
(b) The diameter of the nucleus is of the order of 10–15 m
(c) the space around the nucleus is almost empty. It is filled only with tiny sized electrons which revolve around the nucleus in different orbits.
(d) The electrostatic attraction between the nucleus and electron provides centripetal force required for circular motion
(e) Total positive charge in the nucleus is equal to total –ve charge at the atom.

Drawback of Rutherford Model

(1) The electron orbiting around the nucleus is under acceleration. So it must radiate energy. This may result in radius of orbits decreasing gradually.
(2) According to the Rutherford electron can revolve in all possible orbits hence the atom should emit radiation of all possible wave length. But in reality atoms are found to have line spectrum.

BOHR'S ATOMIC MODEL

In 1913 Bohr gave his atomic theory primarily to explain, the spectra of hydrogen & hydrogen-like atoms. His theory, contained a combination of views from Plank's quantum theory, Einstein's photon concept & Rutherford model of atom. The Bohr theory can explain, the atomic spectra of hydrogen atom & hydrogen-like ions such as He^+, Li^{2+}, Be^{3+}.......(one electron ions). But his theory failed to explain, the spectra of more complex atom and ions. The basic postulates of Bohr's model are

(i) The electron moves in circular orbits around the nucleus under the influence of coulombic force of attraction between the electron and the positively charged nucleus (as shown in figure below).

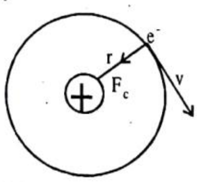


Fig. 9.2 Bohr's model of hydrogen atom

(ii) The electron rotates about the nucleus in certain stationary circular orbits, for which the angular momentum of electron about the nucleus is an integral multiple of $\frac{h}{2\pi} = \hbar$, where h is plank's constant i.e., $mvr = \frac{nh}{2\pi} = n\hbar$ --- (n = 1, 2, 3......... where n is principal quantum number) ...(1)

(iii) When the electron is in one of its stationary orbits, it does not radiate energy, hence the atom is stable.These stationary orbits are called allowed orbits.

(iv) The atom radiates energy when the electron "jumps" from one allowed stationary state to another. The frequency of radiation follows the condition

$hn = E_i - E_f$ ...(2)

Where E_i and E_f are total energies of initial and final stationary states. This difference in energy $(E_i - E_f)$ between two allowed stationary states is radiated/absorbed in the form of a packet of electromagnetic energy (hn - one photon of frequency n) called a photon.

Now, we calculate the allowed energies of hydrogen atom, by using the model shown in fig (i), in which the electron travels in a circular orbital of radius r with an orbital speed v.

For moving an electron in a circular orbit the required centripetal force is provided by the coulomb force of attraction which acts between nucleus [Ze^+, here $Z = 1$ (atomic number) for hydrogen atom] & electron (e^-), i.e.,

$$\frac{mv^2}{r} = \frac{k\,e^2}{r^2} \qquad ...(3)$$

where $k = \frac{1}{4\pi\varepsilon_o}$ is electrostatic constant & ε_0 is permittivity of free space.

Eliminating v from (1) & (3) we obtain

$$r = \frac{n^2\hbar^2}{mke^2} = \frac{\varepsilon_o n^2 h^2}{\pi me^2} \quad (n = 1, 2, 3\ ....) \qquad ...(4)$$

(radius of nth state)

Equation (4) gives the radii of various orbits (have discrete values).

The smallest radius (also called Bohr radius) corresponds to $n = 1$ is

$$r_0 = \frac{\hbar^2}{mke^2} \cong 0.529A° \qquad ...(5)$$

$\Rightarrow$ $r = 0.529\, n^2$ Å for hydrogen atom and $r = 0.529 \times \frac{n^2}{Z}$ for hydrogen like ions.

From equations (4) & (1) we obtain, $v^2 = \frac{n^2\hbar^2}{m^2r^2} = \frac{k^2e^4}{n^2\hbar^2} \Rightarrow v = \frac{ke^2}{n\hbar}$

$$\text{or } v = \frac{e^2}{2\varepsilon_o nh} = \left(\frac{c}{137}\right)\times\frac{1}{n} \text{ (For hydrogen atom)} \qquad ...(6)$$

(velocity in nth state)

$$v = \left(\frac{c}{137}\right)\frac{Z}{n} \text{ for hydrogen like ions}$$

- $\frac{c}{137} = 2.19\times10^6 ms^{-1}$

The total energy of electron is given by

$$E = \text{K.E.} + \text{P.E.} = \text{Kinetic energy} + \text{Potential energy} = \frac{1}{2}mv^2 + \frac{ke(-e)}{r}$$

$$E = \frac{-ke^2}{2r} = \frac{-me^4}{8\varepsilon_o n^2 h^2} \qquad ...(7)$$

(Allowed energy state)

After substituting numerical values in Eq.(7), we obtain

$$E = \frac{-13.6}{n^2}eV \text{ (For hydrogen atom)} \qquad ...(8)$$

$$E = \frac{-13.6Z^2}{n^2}\ eV/\text{atom} \text{ for hydrogen like ions.}$$

KEEP IN MEMORY

1. Total energy = – Kinetic energy = $\frac{\text{Potential energy}}{2}$
2. The reference level for potential energy has been taken as infinity

3. The energy gap between two successive levels decreases as the value of n increases
4. The radius difference between the successive orbit (or shells) increases as the value of n increases
5. The velocity of electrons around the nucleus goes on decreasing as n increases
6. The time period of the electron in an orbit $T^2 \propto r^3$
7. Maximum number of spectral lines that can be emitted when an electron jumps from nth orbit is $\frac{n(n-1)}{2}$
9. The first line of Lyman series is when electron jumps from $2 \to 1$, It is also called α-line
 The second line of lyman series is when electron jumps from $3 \to 1$, It is also called β–line
 The limiting line of lyman series is when electron jumps from $\infty \to 1$

The lowest energy state, or ground state, corresponds to $n = 1$ is

$$E_0 = \frac{-me^4}{8\varepsilon_o h^2} = -13.6eV$$

The next state corresponds to $n = 2$ i.e., first excited state has an energy, $E = -3.4\,eV$

An energy level diagram of the hydrogen atom is shown in figure 2. The upper most level corresponding to $n \to \infty$, represents the state for which the electron is completely removed from the atom.

Energy level diagram for hydrogen atom

Some transitions for Layman, Balmer & Paschen series are shown. The quantum numbers are at left & energies of levels are at right.

In this case ......$E = 0$ for $r = \infty$ (because $n = \infty$)

If the electron jumps from allowed state n_i to allowed state n_f, then frequency of emitted photon is given by

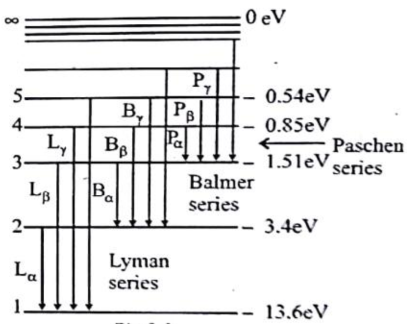


Fig 9.3

$$\nu = \frac{E_f - E_i}{h} = \frac{me^4}{8\varepsilon_o h^3}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \quad ...(9)$$

and the wavelength of emitted photon is $\frac{1}{\lambda} = \frac{\nu}{c} = \frac{me^4}{8\varepsilon_o ch^3}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) \text{ for hydrogen atom} \quad ...(10)$$

and $\bar{\nu} = \frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ (For H-like atoms)

Where $R = 1.096776 \times 10^7 \text{m}^{-1}$ is known as Rydberg constant. By using this expression (i.e., equation 10) we can calculate the wavelengths for various series (Layman, Balmer...) in hydrogen spectrum, i.e.

(i) Layman series $n_i = 1$ & $n_f = 2, 3, 4$...............
(ii) Balmer series $n_i = 2$, & $n_f = 3, 4, 5$...............
(iii) Paschen series $n_i = 3$ & $n_f = 4, 5, 6$..............
(iv) Brackett series $n_i = 4$ & $n_f = 5, 6, 7$...............
(v) P fund series $n_i = 5$ & $n_f = 6, 7, 8$...............

First three series of hydrogen atom are shown in figure. But in practice, the value of Rydberg constant varies between $\frac{R}{2}$ and R

This is because in above calculations we assumed that electron revolves around a massive fixed nucleus of mass M. But in reality, the electron & nucleus each revolve round their common center of mass i.e., the motion of nucleus cannot be ignored. The correction for nuclear motion amounts to replacing electronic mass m by reduced mass μ which is defined as

$$\mu = \frac{\text{mM}}{\text{m} + \text{M}} \quad ...(11)$$

So total energy by taking this correction is

$$E = \frac{-\mu\, e^4}{8\varepsilon_o h^2 n^2} \quad ...(12)$$

If we are dealing with hydrogen like ions such as – He^{+}, Li^{2+}, Be^{3+}, Be^{4+} (one electron ions), each can be considered as a system of two charges, the electron of mass m & charge $-e$ & nucleus of mass M & charge $+Ze$, where Z is atomic number. The radii of circular orbits for these one electron ions can be written as

$$r = \frac{\varepsilon_o n^2 h^2}{\pi \mu Z e^2} = \frac{n^2 \hbar^2}{\mu k Z e^2} \quad (n = 1, 2, 3 \ldots\ldots\ldots\ldots) \qquad \ldots(13)$$

and the allowed energies are given by $E \equiv \frac{-\mu Z^2 e^4}{8 \varepsilon_o h^2 n^2}$ $(n = 1, 2, 3 \ldots\ldots\ldots)$ ...(14)

WAVELENGTH LIMITS IN VARIOUS SPECTRAL SERIES OF HYDROGEN ATOM

(i) For Lyman series (in ultraviolet region)

$\lambda_{max} = 1216$ Å, $\lambda_{min} = 912$ Å

Here $n_i = 1$, $n_f = 2, 3 \ldots\ldots\ldots\ldots\ldots$

(ii) For Balmer Series (in visible region)

$\lambda_{max} = 6563$ Å and $\lambda_{min} = 3646$ Å

Here $n_i = 2$, $n_f = 3, 4, 5 \ldots\ldots\ldots\ldots\ldots$

(iii) For Paschen series (in infrared region)

$\lambda_{max} = 18751$Å and $\lambda_{min} = 8107$ Å

Here $n_i = 3$, $n_f = 4, 5, 6 \ldots\ldots\ldots\ldots\ldots$

(iv) For Brackett series (in infrared region)

$\lambda_{max} = 40477$Å and $\lambda_{min} = 14572$Å

Here $n_i = 4$, $n_f = 5, 6, 7 \ldots\ldots\ldots\ldots\ldots$

(v) For p-fund series (in infrared region)

$\lambda_{max} = 74515$ Å and $\lambda_{min} = 22768$ Å

Here $n_i = 5$, $n_f = 6, 7, 8 \ldots\ldots\ldots\ldots\ldots$

Knowledge ENHANCER

If Bohr's quantization postulate (angular momentum = $nh/2\pi$) is a basic law of nature, it should be equally valid for the case of planetary motion also. Why then do we never speak of quantization of orbits of planets around the sun?

Angular momentum $mvr = n\frac{h}{2\pi}$ associated with planetary motion are incomparably large relative to h. For example angular momentum of Earth in its orbital motion is of the order of $10^{70}\frac{h}{2\pi}$.

For such large value of n, the difference in successive energies and angular momenta of the quantised levels of the Bohr model are so small that one can predict the energy level continuous.

LIMITATIONS OF BOHR'S MODEL

1. It could not explain the spectra of atoms containing more than one electron.
2. There was no theoretical basis for selecting mvr to be an integral multiple of $h/2\pi$.
3. It involved the orbit concept which could not be checked experimentally.
4. It could not explain Zeeman & Stark effect and fine lines of spectra.
5. It was against De-broglie concept and uncertainty principle

KEEP IN MEMORY

1. Energy of electrons in different orbits in an atom varies inversely with the square of the number of orbits. So, energy of electrons increases (decreases in negative) as the orbit becomes higher.
2. If energy of a particular orbit is E for H-atom then its value for a H-like atom with atomic number Z is given by $E' = E \times Z^2$.

3. If the radius of a particular orbit of H-atom is R then its value for a H-like atom is given by $R' = \frac{R}{Z}$.

4. If velocity of an electron in a particular orbit of H-atom be v then its value for a H-like atom is given by $v' = v \times Z$.

5. If kinetic energy and potential energy of an electron in a particular orbit of H-atom be T and V respectively them their corresponding values for a H-like atom are given by $T' = T \times Z^2$ and $V' = V \times Z^2$.

Knowledge ENHANCER

An electron drops from the fourth energy level in an atom to the third level and then to the first level. Two frequencies of light are emitted. How does their combined energy compare with the energy of the single frequency that would have been emitted if the electron had dropped from the fourth level directly to the first level?

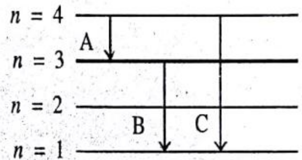


Fig. 9.4

In this figure we have shown the drop of an electron from fourth energy level ($n = 4$) to third energy level ($n = 3$) and during this transition it emits photons of frequency A. In another transition from third energy level ($n = 3$) to first energy level ($n = 1$), it emits photons of frequency B. In case the electron drops from fourth level to first level, it emits photons of frequency C. From the above diagram we can easily see that the sum of frequencies (and energies) for transitions A and B equals the frequency (and energy) of transition C. Energy of transition C = Energy of transition A + Energy of transition B

ILLUSTRATION 9.1

Ionization potential of hydrogen atom is 13.6 eV. Hydrogen atom in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. Which spectral lines will be emitted by hydrogen atoms according to Bohr's theory?

SOLUTION:

Given that $(\text{I.E.})_H = 13.6\, eV$

$\therefore\ (E_1)_H = -(\text{I.E.})_H = -13.6\, eV$.

After absorbing 12.1 eV energy, the energy becomes

$-13.6\, eV + 12.1\, eV = -1.5\, eV$.

This energy corresponds to $n = 3$ level i.e., hydrogen atoms are excited to $n = 3$ level.

Now following three transitions are possible

$n = 3$ to $n = 1$, $n = 3$ to $n = 2$, and $n = 2$ to $n = 1$.

ILLUSTRATION 9.2

The ionisation energy of Hydrogen atom is 13.6 eV. Following Bohr's theory, what is the energy corresponding to a transition between the 3rd and the 4th orbit?

SOLUTION:

$E_n = 13.6/n^2$

$E_3 = -(13.9/9) = -1.51\, eV$

and $E_4 = -(13.6/16) = -0.85\, eV$

Now $E_4 - E_3 = -0.85 - (-1.51) = 0.66\, eV$

ILLUSTRATION 9.3

If the wavelength of the first line of the Lyman series for the hydrogen atom is 1210 Å, then what is the wavelength of the first line of the Balmer series of the hydrogen spectrum ?

SOLUTION:

We know that, $\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

For first line of Lyman series, $n_1 = 1$ and $n_2 = 2$

$\therefore \frac{1}{\lambda_1} = R\left[\frac{1}{1} - \frac{1}{4}\right] = \frac{3R}{4}$ or $R = \frac{4}{3\lambda_1}$

for first line of Balmer series $n_1 = 2$ and $n_2 = 3$

$\therefore \frac{1}{\lambda_2} = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5R}{36} = \frac{5}{36}\left[\frac{4}{3\lambda_1}\right]$

or, $\frac{1}{\lambda_2} = \frac{5}{36} \times \frac{4}{3} \times \frac{1}{1210}$ or, $\lambda_2 = \frac{36 \times 3 \times 1210}{5 \times 4} = 6434\,Å$

ILLUSTRATION 9.4

If the electron in hydrogen atom jumps from the third orbit to second orbit, what is the wavelength of the emitted radiation?

SOLUTION:

$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ or $\frac{1}{\lambda} = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5R}{36}$

$\therefore \lambda = \frac{36}{5R}$

DISCHARGE TUBE EXPERIMENT

- When a very strong potential difference is applied across the two electrodes in a discharge tube and the pressure of the air is lowered gradually, then a stage is reached at which the current begins to flow through the air with cracking noise. The potential at which this happens is called **sparking potential**.
- As pressure is lowered to 0.1 m.m. Hg – cathode glow, Crooke's dark space, negative glow, Faraday dark space and striations are observed.
- At 0.01 m.m. Hg entire tube is dark (Crooke's dark space) except the glass wall behind anode. Colour is yellowish-green for soda glass and greyish-blue for lead glass.
- The luminous streaks travelling from cathode to anode, below 0.01 m.m. Hg, are called **cathode** rays.

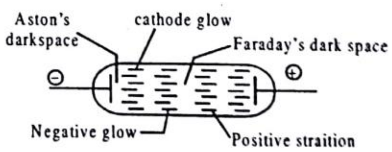


Fig. 9.5

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PROPERTIES OF CATHODE RAYS : Emitted perpendicularly to cathode, travel in straight lines, carry energy, possess momentum, deflected by electric and magnetic fields, excite fluroescence, ionise gas, produce highly penetrating secondary radiation when suddenly stopped, effect photographic plate.

POSITIVE RAYS: Stream of +ve ions moving towards cathode in discharge tube.

PROPERTIES OF POSITIVE RAYS

(i) Rays are made up of positively charged particles.
(ii) Being heavy, their velocity is much less than that of cathode rays.
(iii) They ionise the gas through which they pass and ionising power of positive rays is more than that of cathode rays.
(iv) +ve rays are deflected by electric & magnetic field showing that they carry +ve charge with them.

PHOTO ELECTRIC EFFECT

In 19th century, experiments showed that when light is incident on certain metallic surfaces, electrons are emitted from the surfaces. This phenomenon is known as the photo-electric effect & emitted electrons are called photo electrons. The first discovery of this phenomenon was made by Hertz (shown in fig.).

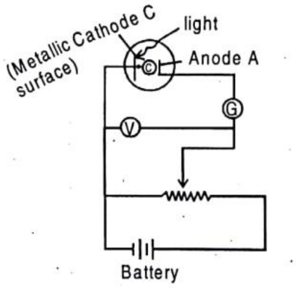

Fig. 9.6 When light strikes the cathode C (metallic surface), photo electrons are ejected. Electrons are collected at Anode A, constituting a current in the circuit. (Photo electric effect)

Figure shows, when light strikes the cathode C, electrons are emitted & they are collected on anode A due to potential difference provided by battery and constitutes the current in the circuit (observed by Galvanometer G.)
A plot of photoelectric current versus the potential difference V between cathode & anode is shown in figure below.

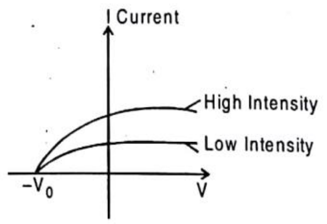

Fig. 9.7 Photoelectric current versus voltage for two light intensities. The current increases with intensity, but reaches a saturation. At voltage less than $-V_0$ the current is zero.

It is clear from figure that photo electric current increases as we increase the intensity of light & obtain saturation value at larger value of potential difference V between cathode & anode. If V is negative then, photoelectrons are repelled by negative anode & only those electrons reaches anode, who have energy equal to or greater than eV. But if V is equal to V_0, called stopping potential (i.e., cut off. potential), no electrons will reach the anode i.e.,

Maximum Kinetic energy of electron = eV_0

or $K_{max} = eV_0$ ...(1)

where e is charge of electron (i.e. 1.6×10^{-19} coulomb).

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But some features of photo electric effect can not be explained by classical physics & the wave theory of light.

(1) No photo electrons are emitted, if the frequency of incident light is less than some cut-off frequency (i.e., threshold frequency) ν_0. It is inconsistent with the wave theory of light, which predicts that photo electric effect occurs at any frequency provided intensity of incident light is sufficiently high.

(2) The maximum kinetic energy of the photo electrons is independent of light intensiy, but increases with increasing the frequency of incident light.

(3) Electrons are emitted from surface almost instantaneously (less than 10^{-9} sec after the surface illumination), even at low intensity of incident light(classicaly we assume that the electrons would require some time to absorb the incident light before they acquire enough kinetic energy to escape from metal).

These above points were explained by Einstein in 1905 by treating the light as stream of particles. Taking Max Planck assumption, Einstein postulated that a beam of light consists of small packets of energy called photons or quanta. The energy E of a photon is equal to a constant h times its frequency ν i.e.,

$$E = h\nu = \frac{hc}{\lambda} \qquad \text{....(2)}$$

Where h is a Universal constant called Planck's constant & numerical value of h is

$$h = 6.62607 \times 10^{-34}\ \text{J.s}$$

When a photon arrives at surface, it is absorbed by an electron. This energy transfer is an All-or-Nothing process, in contrast to continuous transfer of energy in classical theory; the electrons get all photon's energy or none at all. If this energy is greater than the work function ϕ of the metal (ϕ i.e., work function is the minimum energy required to remove the electron from metal surface), the electron may escape from the surface. Greater intensity at a particular frequency means greater number of photons per second absorbed & consequently greater number of electrons emitted per second & so greater current.

To obtain maximum kinetic energy $K_{max} = \frac{1}{2}mv_{max}^2$ for an emitted electron, applied conservation of energy. According to it K_{max} is

$$K_{max} = \frac{1}{2}mv_{max}^2 = h\nu - \phi$$

$$K_{max} = h(\nu - \nu_0) \qquad \text{...(3)}$$

or

$$eV_0 = K_{max} = h(\nu - \nu_0) \qquad \text{...(4)}$$

Where V_0 = cut-off potential

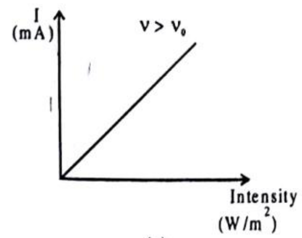
v_{max} = Maximum velocity obtained by photoelectrons

ν = Frequency of incident light i.e., photon

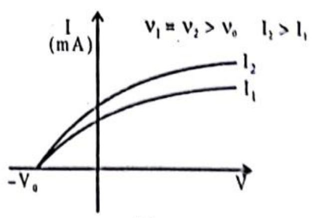
ν_0 = Cut off frequency or threshold frequency.

ν_0 is different for different metallic surfaces. For most metals the threshold frequency is in ultarviolet region of spectrum. (Corresponding to l between 200 & 300 nm), but for potassium & Cesium oxides, it is in the visible spectrum (λ between 400 & 700 nm).

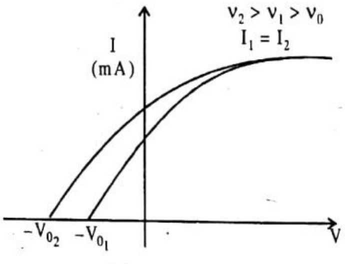
VARIOUS GRAPHS RELATED TO PHOTO ELECTRIC EFFECT



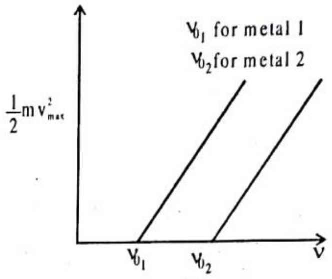
(a)



(b)



(c)



(d)

Fig. 9.8

WORK FUNCTIONS OF SOME ELEMENTS :

Element	(Work function) (eV)
Al (4.3)	Ni (5.1)
C (carbon) (5.0)	Si (4.8)
Cu (4.7)	Ag (4.3)
Au (Gold) (5.1)	Na (2.7)

Where 1 eV = 1.602×10^{-19} joule.

Within the frame work of photon theory of light (Quantum theory of light) we can explain above failures of classical physics.

(1) It is clear from eq. (3) that if energy of photon is less than the work function of metallic surface, the electrons will never be ejected from surface regardless of intensity of incident light.

(2) K_{max} is independent of intensity of incident light, but it depends on the frequency of incident light [i.e., $K_{max} \propto \nu$ (frequency of light)].

(3) Electrons are emitted almost instantaneously consistent with particle view of light in which incident energy is concentrated in small packets (called photons) rather than over a large area (as in wave theory).

Knowledge ENHANCER

Every metal has a definite work function. Why do all photoelectrons not come out with the same energy if incident radiation is monochromatic? Why is there an energy distribution of photoelectrons?

By work function of a metal, we mean the minimum energy required for the electron in the highest level of conduction band to get out of the metal. Since all the electrons in the metal do not belong to that level but they occupy a continuous band of levels, therefore, for the given incident radiation, electrons knocked off from different levels come out with different energies.

X-RAYS

- The X-rays were discovered by Prof. Roentgen, a German scientist in 1885. He was awarded Nobel Prize for this discovery in 1901.
- The modern apparatus for the production of X-rays was developed by Dr. Coolidge in 1913.
- X-rays are produced when fast moving electrons are suddenly stopped on a metal of high atomic number.

Production of X-rays

X-rays are produced when fast moving cathode rays are stopped suddenly by a metal called target.

The modern device used in the production of X-ray is called the Coolidge tube, which consists of a highly evacuated glass tube as shown in the figure.

A filament F emits electrons when it is heated by passing a low current through it. It also acts as a cathode. It is surrounded by a molybdenum cylinder M. The cylinder M focusses the electrons on a fine beam. The target is tungesten which is embedded in copper anode A. The anode A is inclined at 45° to the horizontal. It is cooled by circulating water around it. To produce X-rays, high speed electrons are required. For this, the electrons emitted from the filament are accelerated by applying a high potential difference between the anode and the cathode.

The fast moving electrons produce X-rays when they strike the target.

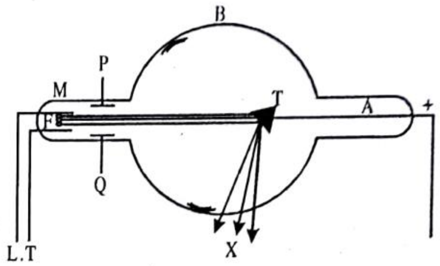


Fig. 9.9 Coolidge tube

Application of x-rays

X-rays have important and useful applications in surgery, medicine, engineering and studies of crystal structures.

1. **Scientific Applications:** The diffraction of X-rays at crystals opened a new dimension to X-rays crystallography. Various diffraction patterns are used for determining internal structure of crystals. The spacing and dispositions of atoms of a crystal can be precisely determined using Bragg's Law : $n\lambda = 2d\sin\theta$.
2. **Industrial Applications:** Since X-rays can penetrate through various materials, they are used in industry to detect defects in metallic structures is Big machines, railway tracks and bridges. X-rays are used to analyse the composition of alloys and pearls.
3. **In Radio Therapy:** X-rays can cause damage to the tissues of body (cells are ionized and molecules are broken). So X-rays damages the malignant growths like cancer and tumors which are dangerous to life, when it used in proper and controlled intensities.
4. **In Medicine and Surgery:** X-rays are absorbed more in heavy elements than in lighter ones. Since bones (containing calcium and phosphorus) absorb more X-rays than the surrounding tissues (containing light elements like H, C, O), their shadow is casted on the photographic plate. So the cracks or Fractures in bones can be easily located. Similarly intestine and digestive system abnormalities are also detected by X-rays.

ILLUSTRATION 9.5

The work function of cesium is 1.8 eV. Light of 5000 Å is incident on it. Calculate (a) threshold frequency and threshold wavelength. (b) maximum K.E. of emitted electrons. (c) maximum velocity of emitted electrons (d) if the intensity of the incident light be doubled, then what will be the maximum K.E. of the emitted electrons? ($h = 6.6\times10^{-34}$ joule second, mass of electron $m = 9.0\times10^{-31}$ kg and speed of light $c = 3\times10^{8}$ m/s).

SOLUTION :

(a) $W_0 = h\nu_0$ or $\nu_0 = h/W_0$

$W_0 = 1.8\times(1.6\times10^{-19}) = 2.9\times10^{-19}$ joule

$$\therefore\ \nu_0 = \frac{W_0}{h} = \frac{2.9\times10^{-19}\text{ joule}}{6.6\times10^{-34}\text{ joule second}}$$

$= 4.4\times10^{14}\ \text{sec}^{-1}$

Threshold wavelength

$$\lambda_0 = \frac{c}{\nu_0} = \frac{3.0\times10^{8}\text{ m/s}}{4.4\times10^{14}\ s^{-1}} = 6.8\times10^{-7}\text{ metre} = 6800\ \text{Å}$$

(b) $E_k = h\nu - W_0 = \dfrac{hc}{\lambda} - W_0$

$$= \frac{(6.63\times10^{-34})(3\times10^{8})}{5000\times10^{-10}} - (2.9\times10^{-19}\text{ joule}) = (4.0-2.9)\times10^{-19} = 1.1\times10^{-19}\text{ joule.}$$

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(c) $E_k = \frac{1}{2} m v_{max}^2$

$$\therefore v_{max} = \sqrt{\left(\frac{2E_k}{m}\right)} = \sqrt{\left[\frac{2 \times (1.1 \times 10^{-19})}{9.0 \times 10^{-31}}\right]}$$

$= 5.0 \times 10^5$ m/sec.

(d) The K.E. of emitted electrons does not depend upon the intensity of light. Hence if the intensity of incident light be doubled, the energy will remain unchanged.

NUCLEAR FISSION

An atom's nucleus can be split apart. When this is done, a tremendous amount of energy is released. The energy is both heat and light energy. Einstein said that a very small amount of matter contains a very large amount of energy. This energy, when let out slowly, can be harnessed to generate electricity. When it is let out all at once, it can make a tremendous explosion in an atomic bomb. The word fission means to split apart. Inside the reactor of an atomic power plant, uranium atoms are split apart in a controlled chain reaction. ${}_{92}U^{235} + {}_0n^1 \longrightarrow {}_{92}U^{236} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1$ + energy

U^{235} nucleus captures a thermal neutron. This forms a compound nucleus U^{236} in excited state.
The shape of nucleus is distorted and nucleus splits into two fragments emitting several neutrons.

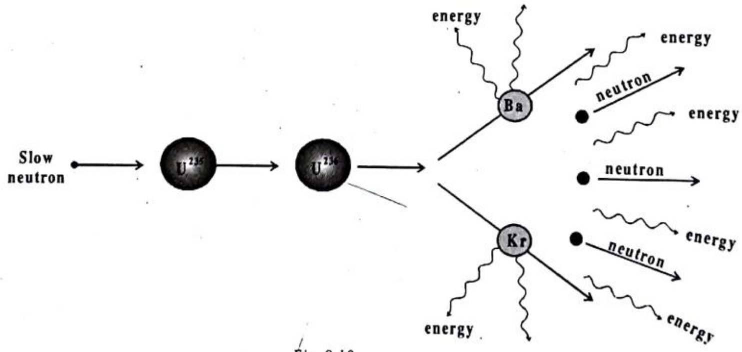

Fig. 9.10

The energy released in fission of Uranium is about 200 MeV. The fission energy released per nucleon is about 0.84 MeV.
In a chain reaction, particles released by the splitting of the atom go off and strike other uranium atoms splitting those. Those particles given off split still other atoms in a chain reaction. In nuclear power plants, control rods are used to keep the splitting regulated so it doesn't go too fast.
If the reaction is not controlled, you could have an atomic bomb. But in atomic bombs, almost pure pieces of the element Uranium-235 or Plutonium, of a precise mass and shape, must be brought together and held together, with great force. These conditions are not present in a nuclear reactor.
The reaction also creates radioactive material. This material could hurt people if released, so it is kept in a solid form. The very strong concrete dome is designed to keep this material inside if an accident happens.

$$\text{Energy released per gm of Uranium} = \frac{\text{Avogadro number}}{\text{mass number}} \times \text{energy released per fission}$$

$$= \frac{6.023 \times 10^{23}}{235} \times 200 = 5.12 \times 10^{23}\,\text{MeV}$$

Energy released by 1gm of $U^{235} = 5.12 \times 10^{23}$ MeV $= 8.2 \times 10^{10}$ J $= 2.28 \times 10^4$ kWh $= 2 \times 10^{10}$ calorie
This energy is equivalent to

(i) energy obtained by burning 2560 kg of coal

(ii) energy obtained by burning 20 tonne of explosive TNT

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The energy is released in form of kinetic energy of fission fragments, γ–rays, heat, sound and light energy.
The fission process can take place at normal pressure and temperature.

NUCLEAR FUSION

Another form of nuclear energy is called fusion. Fusion means joining smaller nuclei to make a larger nucleus. The sun uses energy from nuclear fusion of hydrogen atoms into helium atoms. This gives off heat and light and other radiation.
Also given off in this fusion reaction is energy.
Scientists have been working on controlling nuclear fusion for a long time, trying to make a fusion reactor to produce electricity. But they have been having trouble learning how to control the reaction in a contained space.
Controlled nuclear fusion is believed by many scientists to be the ultimate solution to the world's energy problems. The energy released in fusion reactions is many times greater than that released in fission reactions. To date, however, the technology has not been developed to make use of this source of energy. What's better about nuclear fusion is that it creates less radioactive material than fission, and its supply of fuel can last longer than the sun's.

$$4\,{}_1H^1 \longrightarrow {}_2He^4 + 2\,{}_{+1}e^0 + 2v + Q$$

Fusion is possible at high pressure ($\sim 10^6$ atom) and high temperature ($\sim 10^{8\circ}C$)
The proton-proton cycle happens at lower temperature as compared to carbon-nitrogen cycle.
Nuclear fusion in possible at a place which has reactants in large quantity.
Hydrogen bomb works on principle of nuclear fusion.
The explosion of a hydrogen bomb needs an explosion of atom bomb to generate required temperature.
No harmful radiations are produced in fusion.

COMPARISON OF FISSION AND FUSION

Nuclear fission	Nuclear fusion
1. A heavy nucleus splits into two lighter nuclei.	**1.** Two lighter nuclei join to form a heavy nucleus.
2. Neutrons are required to start fission.	**2.** Protons are usually required to start fusion.
3. It takes place at normal pressure and temperature.	**3.** It takes place at very high pressure and temperature.
4. The energy released per nucleon is small ~ 0.8 MeV.	**4.** The energy released per nucleon is large ~ 6 MeV.
5. Fissionable material is expensive and not easily available.	**5.** Fusion material is cheap and abunduntly available.
6. Energy released in fission per cycle is large ~200 MeV.	**6.** Energy released in fusion per cycle is small ~24.7 MeV.

NUCLEAR REACTORS

A peaceful application of nuclear fission is the generation of electricity using heat from a controlled chain reaction in a nuclear reactor. A nuclear reactor is an arrangement in which the energy produced (in the form of heat) in a nuclear fission can be used in a controlled manner to produce steam, which can run the turbine and produce electricity.

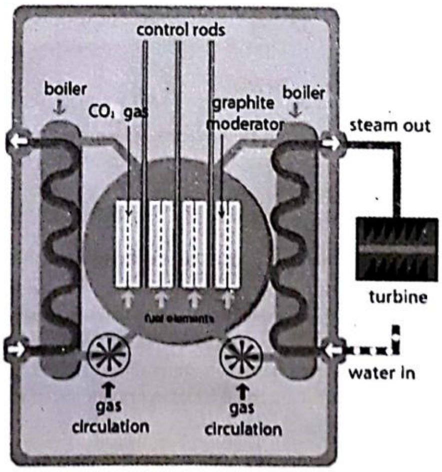

Fig. 9.11 : Nuclear Reactor.

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The main part of nuclear reactor

(a) Nuclear fuel: It is the fissionable material used in nuclear reactors to produce energy by fission process. The nuclear fuel consists of uranium, usually in the form of its oxide, U_3O_8. Naturally occurring uranium contains about 0.7% of uranium 235 isotope which is too low a concentration to sustain a chain reaction. For effective operation of reactor, uranium 235 must be enriched to a concentration of 3 or 4%.

(b) Moderator: An important aspect of the fission process is the speed of the neutrons. Slow neutrons hit uranium-235 nuclei more efficiently than do the fast ones. Because fission reactors are highly exothermic, the neutrons produced usually move with high velocities. For greater collision efficiency, neutrons must be slowed down. For this purposes a substance is used that can reduce the kinetic energy of neutrons. Such a substance is called as a moderator. A good moderator should be a nontoxic and inexpensive substance. And it should resist conversion into radioactive substance by neutron bombardment. Graphite (C) or heavy water (D_2O) are commonly used as moderators.

(c) Control rods: In principle, the main difference between an atomic bomb and nuclear reactor is that the chain reaction that takes place in a nuclear reactor is kept under controlled conditions at all the times. The factor limiting the rate of the reaction is the number of neutrons present. This can be controlled by lowering cadmium or boron rods between the fuel elements.

(d) Coolant: It is the substance which is circulated in pipes to absorb the heat given off by the nuclear reactor and transfer it outside the reactor core, where it is used to produce steam to drive an electric generator. Large quantity of water is used as coolant.

(e) Shield: To prevent the losses of heat and to protect the people operating the reactor from the radiation and heat, the entire reactor core is enclosed in a heavy steel or concrete dome, called the shield.

A complete nuclear power plant essentially consists of the four parts: reactor core, steam generator, steam turbine, and steam condensing system.

ABOUT THE NUCLEUS

Rutherford proposed the existence of a nucleus in 1911 to explain the results of his α scattering experiment. Nucleus is the central core of an atom in which the entire positive charge and almost the entire mass of an atom is concentrated. The nucleus is made of elementary particles called neutrons and protons. All nuclei except hydrogen are made up of neutrons and protons. Hydrogen nucleus contains a single proton.

Neutron is a neutral particle carrying no charge

(i) mass of neutron $m_n = 1.6749 \times 10^{-27}$ kg $= 1.008665$ amu

(ii) they are not deflected by external electric and magnetic fields

(iii) neutrons have high penetrating power and low ionizing power

(iv) neutrons are stable inside the nucleus. Outside the nucleus they are unstable with a half life of about 13 minutes

(v) neutron was discovered by James Chadwick in 1932 when he tried to explain results of collision of α particles with Berrylium

$$_2Be^4 + {}_2He^4 \longrightarrow {}_6C^{13} \longrightarrow {}_6C^{12} + {}_0n^1 + Q$$

(vi) The spin angular momentum of a neutron is $\frac{1}{2}(h/2\pi)$

(vii) depending on speed they are classified as fast and slow (thermal) neutrons.

Proton is a charged particle carrying unit positive charge.

(i) mass of proton $m_p = 1.6726 \times 10^{-27}$ kg $= 1.007825$ amu

(ii) proton was discovered by Goldstein in 1919.

(iii) The number of protons present inside the nucleus of an atom is called atomic number (Z) of an element.

(iv) As atom is electrically neutral so number of protons inside the nucleus is equal to number of electrons in an atom.

According to Heisenberg a proton and neutron can be regarded as two different charge states of same particle called nucleon. The total number of protons and neutrons present inside the nucleus is known as mass number (A) of an element. Number of nucleons or Mass number (A) = proton number (Z) + neutron number (N).

In lighter nuclei the number of neutrons and protons are equal while in heavier nuclei number of neutrons is greater than number of protons.

A nuclide is a specific nucleus of an atom characterized as $_Z X_N^A$ where A is mass number, Z is proton number and N is neutron number

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TYPES OF NUCLEI

Isotopes : These are nuclei of same element having same Z but different A

e.g. $_8O^{16}$, $_8O^{17}$, $_8O^{18}$; $_1H^1$, $_1H^2$, $_1H^3$; $_{92}U^{234}$, $_{92}U^{235}$, $_{92}U^{238}$

All isotopes of an element have same chemical properties. They occupy same place in periodic table. They cannot be separated by chemical analysis. They can be separated by mass spectrometers or mass spectrographs.

Isotones : These are nuclei of different elements having same N but different A.

e.g. $_6C_7^{13}$ & $_7N_7^{14}$; $_1H_2^3$ & $_2He_2^4$; $_2Be_5^9$ & $_5B_5^{10}$

Isotones are different elements with different chemical properties. They occupy different positions in periodic table. They can be separated by chemical analysis and mass spectrometers.

Isobars : These are nuclei of different elements having same A but different N and Z.

e.g $_6C^{14}$ and $_7N^{14}$; $_{18}Ar^{40}$ and $_{20}Ca^{40}$

Isobars are different elements with different chemical properties. They occupy different positions in periodic table. They can be separated by chemical analysis but cannot be separated by mass spectrometers.

Mirror nuclei : These are nuclei with same A but in which neutron and proton number are interchanged.

e.g. $_4Be_3^7$ (Z = 4, N = 3) and $_3Li_4^7$ (Z = 3, N = 4)

Isomer nuclei : These are nuclei with same A and same Z but differ in their nuclear energy states. They have different life times and internal structure. These nuclei have different radioactive properties. e.g. Co^{60} & Co^{60*}

NUCLEAR FORCES

The strong forces of attraction which firmly hold the nucleons in the small nucleus and account for stability of nucleus are called as nuclear forces.

The nuclear force is a short range force

(i) They are appreciable when distance between nucleons is of the order of 2.2×10^{-15} m

(ii) They become negligible when distance between nucleons is greater than 4.2×10^{-15} m

(iii) When distance between two nucleons is less than 1×10^{-15} m the nuclear forces become strongly repulsive

Nuclear forces are charge independent

(a) force between a pair of protons, a pair of neutrons and a pair of neutron and proton is equal.

$F(n-n) = F(p-p) = F(n-p)$

(b) The net force between pair of neutrons and a pair of neutron and proton is equal. This is slightly greater than force between pair of protons because force between protons is reduced due to electrostatic repulsion

Net force $F(n-n)$ = Net force $F(n-p)$ > Net force $F(p-p)$

Nuclear forces are spin dependent

(a) Nuclear force depends on relative orientation of spins between two interacting nucleons.

(b) The force of attraction between two nucleons with parallel spin is greater than force between nucleons with antiparallel spin.

(c) Deutron is formed in a bound state only if spins of neutron and proton are parallel.

Nuclear forces show saturation property

(a) The nucleon in nucleus interacts with its nearest neighbour only.

(b) It remains unaffected by the presence of other surrounding nucleons.

(c) The nuclear force between a pair of nucleons in light and heavy nucleus is equal.

Nuclear forces are non-central forces

(a) They do not act along line joining the centre of two nucleons.

(b) The non-central component depends on orientation of spins relative to line joining the centre of two nucleons.

Size of nucleus : Rutherford in his α scattering experiment calculated the distance of closest approach at which α particle approaching nucleus is turned around by Coulomb repulsion.

When α particle is turned the kinetic energy must be converted to electric potential energy since collision is elastic

$$\frac{1}{2}mv^2 = \frac{K(2e)\,(Ze)}{d}, \text{ distance of closest approach } d = \frac{4K\,Ze^2}{mv^2}$$

for gold $Z = 79$, $\frac{1}{2}mv^2 = 7MeV = 7\times1.6\times10^{-13}J$

so, $d = \dfrac{2\times9\times10^9\times79\times(1.6\times10^{-19})^2}{7\times1.6\times10^{-13}} = 3.2\times10^{-14}$m

Rutherford assumed the distance of closest approach as a measure of size of nucleus.
Radius of nucleus is related to mass number as $R = R_0A^{1/3}$ where R_0 is constant & $R_0 = 1.25\times10^{-15}$m

Density of nucleus : Volume of nucleus $V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A$ So volume $V \propto A$

mass of nucleus = mass of protons + mass of neutrons = mA where m is mass of one nucleon

density of nucleus $\rho = \dfrac{\text{mass of nucleus}}{\text{volume of nucleus}} = \dfrac{mA}{\frac{4}{3}\pi R_0^3 A} = \dfrac{3m}{4\pi R_0^3}$

The nuclear density is independent of mass number A.

The nuclear density is nearly constant and is equal to $\rho = \dfrac{3m}{4\pi R_0^3} = \dfrac{3\times1.67\times10^{-27}}{4\times3.14\times(1.25\times10^{-15})^3} = 2.04\times10^{17}\,\text{kg/m}^3$

The nuclear density is maximum at centre of nucleus and decreases as one moves away from the centre.
The distance from the centre of nucleus where density becomes 50% of its density at centre is called nuclear radius.
The high density of nucleus indicates compactness of nucleus.

Atomic mass unit : 1 atomic mass unit (amu) = $\frac{1}{12}$ of mass of carbon ($_6C^{12}$) atom

$1\text{ amu} = \frac{1}{12}\left(\frac{12}{6.023\times10^{23}}\right) = 1.66\times10^{-24}\,g = 1.66\times10^{-27}$ kg

Energy equivalent to 1 amu mass, $E = mc^2 = 1.66\times10^{-27}(3\times10^8)^2$ joule $= 1.49\times10^{-10}$ joule $= 931.5$ MeV
1 amu $= 1.49\times10^{-10}$ J $= 931.5$ MeV

MASS DEFECT

The mass of the nucleus is always less than the sum of masses of nucleons composing the nucleus. The difference between the rest mass of nucleus and sum of rest masses of nucleons constituting the nucleus is known as mass defect.
Mass defect $\Delta m = [Zm_p + (A-Z)m_n] - M(_ZX^A)$

BINDING ENERGY

The energy required to break a nucleus into its constituent nucleons and place them at infinite distance is called binding energy. The energy equivalent to mass defect is called binding energy. This is the energy with which the nucleons are held together. The binding energies (~MeV) are very large as compared to molecular binding energies (~eV)

Binding energy $BE = (\Delta m)c^2 = c^2[Zm_p + (A-Z)m_n - M(_ZX^A)]$

rest mass of protons + rest mass of neutrons = rest mass of nucleus + BE

NUCLEAR REACTION

The transformation of one stable nucleus into another nucleus by bombardment with suitable high energy particles like proton, neutron, α particle etc is known as nuclear reaction.

$$\underset{\text{Target nucleus}}{_ZX^A} + \underset{\text{projectile}}{_2He^4} \longrightarrow \underset{\text{compound nucleus}}{_{Z+2}C^{A+4}} \longrightarrow \underset{\text{product nucleus}}{_{Z+1}Y^{A+3}} + {_1H^1} + \underset{\text{energy change}}{Q}$$

e.g. $_{13}Al^{27} + {_2He^4} \longrightarrow {_{15}P^{31}} \longrightarrow {_{14}Si^{30}} + {_{+1}e^0} + {_0n^1} + Q$

The nuclear reactions obey following conservation laws

(a) conservation of linear momentum (b) conservation of total energy (c) conservation of charge
(d) conservation of number of nucleons. (e) conservation of angular momentum.

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ILLUSTRATION 9.6

What is the power output of $_{92}U^{235}$ reactor if takes 30 days to use up 2 kg of fuel, and if each fission gives 185 MeV of usable energy? Avogadro's number $N = 6.02 \times 10^{26}$ per kilomole.

SOLUTION:

Number of atoms in 2kg fuel

$= \frac{2}{235}$ kilomole $\times (6.02 \times 10^{26}$ per kilomole)

$= 5.12 \times 10^{24}$

fission rate = number of atoms fissioned in 1 sec.

$$= \frac{5.12 \times 10^{24}}{30 \times 24 \times 60 \times 60} = 1.975 \times 10^{18} \text{ per second}$$

Each fission gives 185 MeV of energy.

Hence energy obtained in one second i.e. power output

$P = 185 \times (1.975 \times 10^{18})$ MeV per second

$= 185 \times (1.975 \times 10^{18}) \times (1.6 \times 10^{-19})$ joule

$= 58.46 \times 10^{6}$ joule per second (watt)

$= 58.46$ mega-Watt

ILLUSTRATION 9.7

Calculate the binding energy per nucleon for $_{17}C^{35}$. Given $M(Cl^{35}) = 34.9800$ amu $m_n = 1.008665$ amu and $m_p = 1.007825$ amu.

SOLUTION:

$BE = Zm_p + (A - Z)\,m_n - M(Cl^{35}) = 17 \times 1.007825 + 18 \times 1.008665 - 34.9800 = 0.308995$ amu

$BE = 0.308995 \times 931.5 = 287.83$ MeV

$$\bar{B} = \frac{BE}{A} = \frac{287.75}{35} = 8.22 \text{ MeV / nucleon}$$

ILLUSTRATION 9.8

A star initially has 10^{40} deutrons. It produces energy by processes.

$$_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + p$$

and $_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + n$

If average power radiated by star is 10^{16}W find time in which deutron is exhausted.

$M(_1H^2) = 2.01471$ amu $\quad M(_2He^4) = 4.00388$ amu

$M_p = 1.00783$ amu $\quad m_n = 1.00866$ amu

SOLUTION:

Adding the two equation $3\,{}_1H^2 \longrightarrow {}_2He^4 + p + n$

mass defect $= 3 \times 2.01471 - 4.00388 - 1.00783 - 1.00866 = 0.02376$ amu $= 0.02376 \times 931.5$ MeV $= 22.13$ MeV

Power of star $= 10^{16}$W $= 10^{16}$ J/S

Number of deutrons used per second

$$= \frac{10^{16}}{1.6 \times 10^{-19} \times 22.13 \times 10^{6}} = 2.82 \times 10^{27}$$

Time in which deutrons will be used

$$= \frac{\text{number of deutrons}}{\text{number of deutrons used per second}} = \frac{10^{40}}{2.82 \times 10^{27}} = 3.5 \times 10^{12} \text{ sec.}$$

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RADIOACTIVITY

The phenomenon of spontaneous emission of radiations from a substance is called radioactivity
Radioactivity was discovered by Henry Becquerel in 1896 in Uranium salts. The substances like Uranium, Radium, Thorium, Polonium etc. which show radioactivity are called radioactive substances. Nuclei with Z > 83 spontaneously disintegrate with emission of α and β particles. In radioactivity emission of alpha (α), Beta (β) and gamma (γ) radiation takes place. These are called radioactive radiations or Becquerel rays. The simultaneous emission of α and β particles is not possible. Only one particle is emitted at a time. The emission of radiations causes a change in structure of nucleus. This causes transformation of an atom to new lighter atom or changes a radioactive element into element of lower atomic weight. All heavier radioactive elements emit radiations till they are converted to stable $_{82}Pb^{206}$. It is a statistical process, so it is governed by the laws of probability. The disintegration of all atoms has equal probability. It is a spontaneous process which is independent of all external conditions. It is not affected by temperature, pressure, electric or magnetic field.

Types of radioactive processes

(a) Alpha decay

$_ZX^A$ (parent nucleus) $\longrightarrow$ $_{Z-2}Y^{A-4}$ (daughter nucleus) + $_2He^4$ (alpha particle)

e.g. $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_2He^4$

Alpha particle consists of 2 neutrons, 2 protons and carries positive charge in magnitude 2 electrons. It is doubly ionized helium nuclei. α emission takes place when size of nucleus becomes too large. The decay reduces the size of nucleus. α emission is explained on basis of quantum mechanical tunnel effect. The energy released in α decay $Q = (M_x - M_y - M_\alpha)c^2$. The kinetic energy of α particle $E_\alpha = \left(\frac{A-4}{A}\right)Q$. Where A is mass number and Q is disintegration energy.

(b) Beta decay

(a) Electron emission (β^-)

$_ZX^A \longrightarrow {}_{Z+1}Y^A + {}_{-1}e^0$ (β^- particle) + $\bar{\nu}$

e.g. $_6C^{14} \longrightarrow {}_7N^{14} + {}_{-1}e^0 + \bar{\nu}$ (antineutrino)

β^- particles are fast moving electrons carrying negative charge. They are emitted when nucleus has too many neutrons relative to number of protons i.e. N/Z ratio is larger than required. The emission of electron takes place when a neutron is converted to proton inside the nucleus. This helps in correction of N/Z ratio.

$$_0n^1 \longrightarrow {}_1p^1 + {}_{-1}e^0 + \bar{\nu}$$

The interaction responsible for β decay is weak interaction.

(b) Positron emission

$_ZX^A \longrightarrow {}_{Z-1}X^A + {}_{+1}e^0$ (β^+ particle) + ν

eg. $_{29}Cu^{64} \longrightarrow {}_{28}Ni^{64} + {}_{+1}e^0 + \nu$ (neutrino)

β^+ particles are positrons with mass equal to an electron but carry a unit positive charge. They are emitted when nucleus has too many protons relative to number of neutrons i.e. N/Z ratio is smaller than required. The emission of positron takes place when a proton is converted to neutron inside the nucleus. This increases N/Z ratio.

$_1p^1 = {}_0n^1 + {}_{+1}e^0 + \nu$

(c) Gamma decay

$$_ZX^{A*} \longrightarrow {}_ZX^A + \gamma$$

e.g. $_5B^{12} \longrightarrow {}_6C^{12*} + {}_{-1}e^0 + \bar{\nu}$

$$_6C^{12*} \longrightarrow {}_6C^{12} + \gamma$$

γ rays are electromagnetic radiations which are chargeless, massless and emitted when nucleus has excess energy. They are emitted when nucleus jumps from excited state to lower level or ground state. This reduces the energy of nucleus. They are electromagnetic radiations of short wavelength (~10^{-12}m) which travel with speed of light.

(d) Electron capture

$_ZX^A + {}_{+1}e^0 \longrightarrow + {}_{Z-1}Y^A + \nu$

$_4Be^7 + {}_{-1}e^0 \longrightarrow {}_3Li^7 + \nu$

This process takes place when nucleus has too many protons relative to number of neutrons. i.e. N/Z ratio is larger than required. In the process parent nucleus captures one of its own orbital atomic electron and emits a neutrino.

Properties of α, β and γ rays

Property	α – rays	β – rays	γ – rays
1. Nature	These are doubly ionized helium atom $_2He^4$ charge $q = +2e = 3.2 \times 10^{-19} C$ mass $m = 2p + 2n = 4amu$ $= 4 \times 1.6 \times 10^{-27}$ kg	These are beam of fast moving electrons (β^-) and positions (β^+) charge $\beta^- = -e = -1.6 \times 10^{-19} C$ $\beta^+ = +e = 1.6 \times 10^{-19} C$ m (β^-) = m(β^+) = 9.1×10^{-31} kg	These are electromagnetic radiations of high frequency and travel in form of photons. charge q = 0 (chargeless) rest mass = 0 effective mass = $\frac{h\nu}{c^2} = \frac{h}{\lambda c}$
2. Velocity	Speed ranges between 1.4×10^7 to 2.20×10^7 m/s $v_\alpha \sim 0.05$ c	speed ranges from 1% to 90% of velocity of light $v_\beta \sim 0.9c$	speed equals velocity of light $v_\gamma = c$
3. Ionising power	These have maximum ionizing power (1000)	There ionizing power is less than α particles and more than γ rays (100)	There ionizing power is least (1)
4. Penetration power	The penetration power is smallest. Can only penetrate through 0.01 mm thick Al sheet (1)	Penetration power is about 100 times that of α rays, can penetrate through 1 mm thick Al sheet (100)	Penetration power is very large. Can penetrale about 30 cm thick Al sheet (10000)
5. Range	Range is very small (few cms in air)	Range is more than α rays. (few meters in air)	Range is very large (many hundreds of meter in air)
6. Nature of spectrum	Line spectrum	continuous spectrum	line spectrum
7. Interaction with matter	produces heat	produces heat	produces photoelectric effect Compton effect, pair production
8. Effect of electric and magnetic field	Suffers small deflection	suffers large deflection	pass undeflected
9. Effect of photo graphic plate and ZnS	Affects photographic plate and produces fluorescense	Affects photographic plate and produces fluorescence	Affects photographic plate and produces fluorescence.

SODDY AND FAJAN'S DISPLACEMENT LAWS

1. **For α decay :** When an element emits an α particle, the new element has mass number A reduced by 4 and atomic number Z reduced by 2. The new element is displaced by two places on left in periodic table.

   $${}_ZX^A \longrightarrow {}_{Z-2}Y^{A-4} + {}_2He^4$$

2. **For β⁻ decay :** When an element emits a β^- particle the mass number A remains unchanged and atomic number Z is increased by 1. The new element is displaced by one place on right in periodic table

   $${}_ZX^A \longrightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \text{antineutrino } (\bar{\nu})$$

3. **For β⁺ decay :** When an element emits a β^+ particle the mass number remains unchanged and atomic number Z is decreased by one. The new element is displaced by one place on left in periodic table

   $${}_ZX^A \longrightarrow {}_{Z-1}Y^A + {}_{+1}e^0 + \text{neutrino } (\nu)$$

4. **For γ decay :** When an element emits a γ particle the mass, charge or position of element in periodic table remains unchanged. Here the excited nucleus returns to ground state by emission of γ ray photon.

RUTHERFORD – SODDY LAWS

The disintegration of a radioactive substance is random and spontaneous. Radioactive decay is purely a nuclear phenomenon and is independent of any physical and chemical conditions. The radioactive decay follows first order kinetics, i.e., the rate of decay is proportional to the number of undecayed atoms in a radioactive substance at any time t. If dN be the number of atoms (nuclei) disintegrating in time dt, the rate of decay is given as dN/dt. From first order of kinetic rate law: $\frac{dN}{dt} = -\lambda N$ where λ is called as decay or disintegration constant.

Let N_0 be the number of nuclei at time $t = 0$ and N_t be the number of nuclei after time t, then according to integrated first order rate law, we have:

$$N_t = N_0 e^{-\lambda t} \Rightarrow \lambda t = \ln\frac{N_0}{N_t} = 2.303\log\frac{N_0}{N_t}$$

The fraction of active atoms remaining at time t is $\frac{N}{N_0} = e^{-\lambda t}$

The number of atoms that have decayed in time t is

$$N_0 - N = N_0(1 - e^{-\lambda t})$$

The fraction of atoms that have decayed in time t is

$$\frac{N_0 - N}{N_0} = 1 - e^{-\lambda t}$$

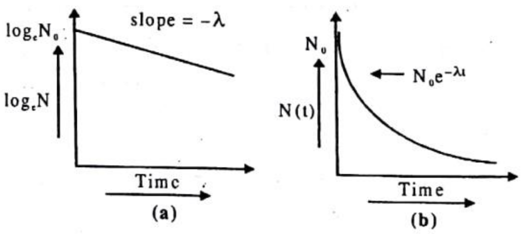

Fig. 9.12

Decay Constant

Decay Constant $\lambda = \frac{-dN/dt}{N} = \frac{\text{rate of decay}}{\text{number of active atoms}}$

Decay Constant is rate of decay of radioactive atoms per active atom.

At $t = \frac{1}{\lambda}$; $\quad N = \frac{N_0}{e}$

The decay constant of radioactive element is equal to reciprocal of the time after which number of remaining active atoms reduce to 1/e times of original value.

At $t = \frac{1}{\lambda}$ fraction of active nuclei left $\frac{N}{N_0} = \frac{1}{e} = 0.37$ or 37%

fraction of decayed nuclei $1 - \frac{N}{N_0} = 0.63 = 63\%$

$\lambda = \frac{dN/N}{dt}$. The decay constant is the probability of decay per active atom per unit time.

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Unit of decay constant is second^{-1} and dimension is T^{-1}

If their are more than one radioactive elements in a group then the resultant decay Constant is equal to sum of individual decay constants.

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + ... \text{or} \quad \frac{1}{T} = \frac{1}{T_1} + \frac{1}{T_2} + ...$$

Half life (T) : Period of a radioactive substance is defined as the time in which one-half of the radioactive substance is disintegrated. If N_0 be the number of nuclei at $t = 0$, then in a half life T, the number of nuclei decayed will be $N_0/2$.

$$N_t = N_0 e^{-\lambda t} \quad ...(i) \qquad \frac{N_0}{2} = N_0 e^{-\lambda T} \quad ...(ii)$$

From (i) and (ii) $\quad \frac{N_t}{N_0} = \left(\frac{1}{2}\right)^{t/T} = \left(\frac{1}{2}\right)^n$ k $\qquad n$: number of half lives

Mean life (τ) : The mean life of an atom in a radioactive substance is called average life of radioactive substance.

Mean life $\quad \tau = \dfrac{\text{the sum of lives of all active atoms}}{\text{total number of active atoms}}$ or $\tau = \dfrac{\int_0^{N_0} t\,dN}{N_0} = \dfrac{N_0\lambda \int_0^{N_0} t\, e^{-\lambda} dt}{N_0} = \dfrac{1}{\lambda}$

Thus mean life is equal to reciprocal of decay constant $(\tau = 1/\lambda)$

Half life $T = \dfrac{0.693}{\lambda} = 0.693\tau$ and average life $\tau = \dfrac{T}{0.693} = 1.44T$

$\tau > T$ i.e. average life is greater than half life.

Mean life is the time in which (a) number of active atoms reduces to 37% of its initial value or (b) number of decayed atoms is 63%

$N = N_0 e^{-\lambda t}$ so $\log \dfrac{N}{N_0} = -\lambda t$

Mean life is equal to magnitude of reciprocal of slope of $\log \dfrac{N}{N_0}$ v/s t curve.

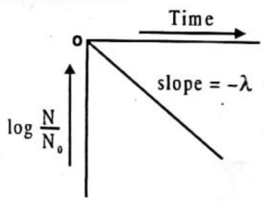

Fig. 9.13

ACTIVITY

The number of decays per unit time or decay rate is called activity.

Activity $A = \dfrac{dN}{dt} = N_0 \lambda e^{-\lambda t} = A_0 e^{-\lambda t} = N\lambda$

where $N_0 \lambda = A_0$ is initial activity

$A = A_0 e^{-\lambda t}$ is the activity law which shows activity decreases exponentially with time.

The activity of one gram of radioactive substance called specific activity.

Units of activity

Curie : The specific activity of 1 gm of Radium 226 is called one curie.

1 curie = 3.7×10^{10} disintegrations per second

Rutherford : 1 rutherford = 10^6 disintegrations per second

Becquerel : 1 Becquerel = 1 disintegration per second

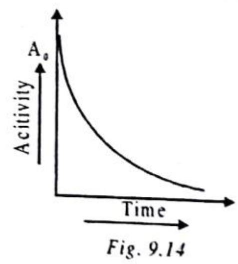

Fig. 9.14

ILLUSTRATION 9.9

At any instant, the ratio of the amount of radioactive substances is 2 : 1. If their half lives be respectively 12 and 16 hours. then after two days, what will be the ratio amount of the substances?

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SOLUTION :

For first substance $n = \frac{48}{12} = 4$

$$\therefore \; N_1 = N_{01}\left(\frac{1}{2}\right)^4 = N_{01}/16 \qquad ...(1)$$

For second substance, $n = \frac{48}{16} = 3$

$$N_2 = N_{02}\left(\frac{1}{2}\right)^3 = N_{02}/8 \qquad ...(2)$$

Now, $\frac{N_1}{N_2} = \frac{N_{01}}{N_{02}} \times \frac{1}{2} = 2 \times \frac{1}{2} = 1$ ($\because$ $N_{01} = 2N_{02}$)

$\therefore \; N_1 : N_2 = 1 : 1$

ILLUSTRATION 9.10

Two radioactive substances X and Y initially contain equal number of nuclei. X has a half life of 1 hour and Y has half life of 2 hours. After two hours what is the ratio of the activity of X to the activity of Y ?

SOLUTION :

$$\frac{dN_x}{dt} = \lambda_1 N_x = \lambda_1 (N_0/4) \qquad (\because N = N_0/2^n) \text{ and } \frac{dN_Y}{dt} = \lambda_2 N_Y = \lambda_2 (N_0/2)$$

$$\therefore \left(\frac{dN_X}{dt}\right) \Big/ \left(\frac{dN_Y}{dt}\right) = \frac{\lambda_1}{2\lambda_2} = \frac{T_2}{2T_1} = \frac{2}{2\times1} = \frac{1}{1} \qquad \left(\because \lambda = \frac{0.693}{T}\right)$$

ILLUSTRATION 9.11

The half life of radium is 1620 years and its atomic weight is 226. What will be the number of atoms that will decay from its 1 gm sample per second?

SOLUTION :

According to Avogadro's hypothesis,

$$N_0 = \frac{6.02 \times 10^{23}}{226} = 2.66 \times 10^{21}$$

$$\text{Half life} = T = \frac{0.6931}{\lambda} = 1620 \text{ years}$$

$$\therefore \; \lambda = \frac{0.6931}{1620 \times 3.16 \times 10^7} = 1.35 \times 10^{-11} \, s^{-1}$$

Because half life is very much large as compared to its time interval, hence $N \approx N_0$

$$\frac{dN}{dt} = \lambda N = \lambda N_0 \quad \text{or} \quad dN = \lambda N_0 dt$$

$$\therefore \; dN = (1.35 \times 10^{-11})\,(2.66 \times 10^{21})(1) = 3.61 \times 10^{10}.$$

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ILLUSTRATION 9.12

One gram of Radium emits 3.7×10^{10} a particles per second. Calculate half life and mean life of Radium. Given Atomic mass of Radium = 226

SOLUTION :

Rate of decay of Radium = rate of emission of α particles

or $\frac{-dN}{dt} = \lambda N = 3.7 \times 10^{10}$ per second

Number of active atoms $N = \frac{6.023 \times 10^{23} \times 1}{226}$

$\therefore \ \lambda N = \frac{0.693}{T} \times \frac{6.023 \times 10^{23}}{226} = 3.7 \times 10^{10}$

or $T = 1583$ years

Mean life $\tau = 1.44\,T = 1.44 \times 1580 = 2279$ years

ILLUSTRATION 9.13

The activity of a radioactive substance drops to 1/32 of its initial value in 7.5 h. Find the half life.

SOLUTION :

Using $\frac{A}{A_0} = \left(\frac{1}{2}\right)^{t/T}$ or $\frac{1}{32} = \left(\frac{1}{2}\right)^{7.5/T}$

or $\left(\frac{1}{2}\right)^5 = \left(\frac{1}{2}\right)^{7.5/T}$ or $5 = \frac{7.5}{T}$ i.e. $T = 1.5$ hours

MISCELLANEOUS SOLVED EXAMPLES

1. Find the ratio of the area of orbit of first excited state of electron to the area of orbit of ground level for hydrogen atom.

Sol. $A \propto r^2 \propto n^4$

$$\frac{A_2}{A_1} = \left[\frac{2}{1}\right]^4 = \frac{16}{1} = 16:1$$

2. The activity of a radioactive substance drops to 1/32 of its initial value in 7.5 h. Find the half life.

Sol. Using $\frac{A}{A_0} = \left(\frac{1}{2}\right)^{t/T}$ or $\frac{1}{32} = \left(\frac{1}{2}\right)^{7.5/T}$

or $\left(\frac{1}{2}\right)^5 = \left(\frac{1}{2}\right)^{7.5/T}$ or $5 = \frac{7.5}{T}$

i.e. $T = 1.5$ hours

3. The half life of a radioactive substance is 34.65 minute. If 10^{22} atoms are active at any time then find the activity of substance?

Sol. Activity $A = \frac{-dN}{dt} = \lambda N$

$$A = \frac{0.693}{T} \times N = \frac{0.693}{34.65 \times 60} \times 10^{22}$$

$= 3.34 \times 10^{18}$ disintegration /sec.

4. The mean life of a radioactive material for α and β decay are 1620 years and 520 years. What is the half life of sample.

Sol. There are two channels of decay so $\frac{1}{\tau} = \frac{1}{\tau_\alpha} + \frac{1}{\tau_\beta}$

or $\tau = \frac{\tau_\alpha \tau_\beta}{\tau_\alpha + \tau_\beta} = \frac{1620 \times 520}{1620 + 520} = 394$ years

The half life $T = 0.693\tau = 0.693 \times 394 = 273$ years

5. A nucleus breaks into two parts whose velocity is in ratio 2:1. Find the ratio of their radius.

Sol. as per conservation of momentum $m_1 v_1 + m_2 v_2 = 0$

So $\frac{m_1}{m_2} = \frac{v_2}{v_1}$

ratio of radii $\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{m_1}{m_2}\right)^{1/3} = \left(\frac{1}{2}\right)^{1/3}$

so $R_1 : R_2 = 1 : 2^{1/3}$

6. The binding energy of $_{10}Ne^{20}$ is 160.64 *MeV*. Find the atomic mass.

Sol. Given $m_P = 1.007825$ amu and $m_n = 1.008665$ amu
$BE = \Delta mc^2 = c^2\,[Zm_P + (A - Z)\,m_n - M]$

$M = Zm_p + (A - Z)\,m_n - BE(\text{amu})$

$$M = 10 \times 1.007825 + 10 \times 1.008665 - \frac{160.64}{931.25} = 19.992 \text{ amu.}$$

7. The mass defect in a nuclear fusion reaction is 0.3%. What amount of energy is produced when 1kg of substance undergoes fusion.

Sol. Total mass converted to energy $= \frac{0.3}{1000} \times 1 = 3 \times 10^{-3}$ kg

Energy liberated $= \Delta mc^2 = 3 \times 10^{-3} \times (3 \times 10^8)^2$
$= 27 \times 10^{13}$ joule

8. Determine the power output of a $_{92}U^{235}$ reactor if it takes 30 days to use 2kg of fuel. Energy released per fission is 200 MeV and N = 6.023×10^{26} per kilomole.

Sol. Number of atoms in 2kg fuel

$$= \frac{2}{235} \times 6.023 \times 10^{26} = 5.12 \times 10^{24}$$

Number of fission per second

$$= \frac{5.12 \times 10^{24}}{30 \times 24 \times 60 \times 60} = 1.978 \times 10^{18}$$

Energy released per fission
$= 200 \text{ MeV} = 200 \times 1.6 \times 10^{-13} = 3.2 \times 10^{-11}$ J

Power output $= 3.2 \times 10^{-11} \times 1.978 \times 10^{18} = 63.28 \times 10^6\ W$
$= 63.28\ MW$

9. If 200 MeV energy is released per fission of U^{235} nuclei. Find the mass of U^{235} consumed per day in a reactor of power 1MW assuming its efficiency as 80%.

Sol. Energy produced in one day $= 10^6 \times 24 \times 60 \times 60$ joule

$$\eta = 0.8 = \frac{\text{output energy}}{\text{input energy}} = \frac{10^6 \times 24 \times 60 \times 60}{\text{input energy}}$$

So input energy $= \dfrac{10^6 \times 24 \times 60 \times 60}{0.8} = 10.8 \times 10^{10}$ J

energy released in one fission
$= 200 \times 10^6 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-11}$ J

no. of fissions per day $= \dfrac{10.8 \times 10^{10}}{3.2 \times 10^{-11}} = 3.375 \times 10^{21}$

mass of U^{235} required
= no. of nuclei disintegrating per day × mass of U^{235}
$= 3.375 \times 10^{21} \times 235 \times 1.67 \times 10^{-27} = 1.324$ mg

10. Ultraviolet light of wavelength 2271Å from a 100 W mercury source irradiates a photo-cell made of molybdenum metal. If the stopping potential is – 1.3 V, estimate the work function of the metal. How would the photo-cell respond to a high intensity ($\sim 10^5$ W m^{-2}) red light of wavelength 6328Å produced by a He-Ne laser?

Sol. Let us find energy of each photon of given ultraviolet light

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2271 \times 10^{-10} \times 1.6 \times 10^{-19}} = 5.47 \text{ eV}$$

Maximum kinetic energy of emitted electron can be judged by stopping potential of 1.3 volt.

$$\frac{1}{2}mv_{\max}^2 = 1.3 \text{ eV}$$

Using Einstein's equation $h\upsilon = W_0 + \frac{1}{2}mv_{\max}^2$

$5.47 \text{ eV} = W_0 + 1.3 \text{ eV}$

$W_0 = 4.17 \text{ eV}$

Red light of wavelength 6328Å will have energy of each photon

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{6328\times10^{-10}\times1.6\times10^{-19}} = 1.96 \text{eV}$$

Thus energy of red light photons is less than work function 4.17 eV, hence irrespective of any intensity no emission will take place.

11. The total energy of an electron in the first excited state of the hydrogen atom is about – 3.4 eV.
(a) What is the kinetic energy of the electron in this state?
(b) What is the potential energy of the electron in this state?
(c) Which of the answer above would change if the choice of the zero of potential energy is changed?

Sol. Kinetic energy of an electron in an orbit, $= \frac{1}{4\pi\varepsilon_0}\frac{e(Ze)}{2r}$ ...(i)

Potential energy of electron in the orbit $U = -\frac{1}{4\pi\varepsilon_0}\left(\frac{Ze^2}{r}\right)$ ...(ii)

Total energy $E = K + U = -\frac{1}{4\pi\varepsilon_0}\left(\frac{Ze^2}{2r}\right) = -K = \frac{U}{2}$

It is given, total energy $E = (-3.4 \text{ eV})$

(a) Kinetic energy of electron in this state $E = -K$

So, $K = E = -(-3.4 \text{ eV}) = 3.4 \text{ eV}$

(b) Potential energy $E = U/2$

$U = 2E = 2(-3.4) = -6.8 \text{ eV}$

(c) If the zero of the potential energy is chosen differently, the kinetic energy remain the same. Althugh potential energy and hence total energy changes.

12. A radioactive isotope has a half-life of T years. How long will it take the activity to reduce to (a) 3.125%, (b) 1% of its original value?

Sol. Activity $R = R_0e^{-\lambda t}$

Also instantaneous activity, $R = -\lambda N$

$$R = -\frac{0.693}{T}N$$

Initital activity, $R_0 = -\lambda N_0$

So, $R_0 = -\frac{0.693}{T}N_0$

(a) $\frac{R}{R_0} = \frac{N}{N_0} = \frac{3.125}{100} = \frac{1}{32}$ or $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^5$ or $n = 5$

$\therefore t = nT = 5T$ years.

(b) $\frac{R}{R_0} = \frac{N}{N_0} = \frac{1}{100}$

Required time, as can not be solved by direct calculation as in part (a).

$$t = \frac{2.303}{\lambda}\log\frac{N_0}{N} = \frac{2.303T}{0.693}\log 100 = \frac{2.303\times2\times T}{0.693} \approx 6.65T \text{ years.}$$

13. The half-life of $^{90}_{38}Sr$ is 28 years. What is the distintegration rate of 15 mg of this isotope?

Sol. Given $T_{1/2} = 28$ years $= 28 \times 3.154 \times 10^7 s$

Mass $m = 15$ mg $= 0.015g$

Number of atoms in 0.015g sample of $^{80}_{38}Sr$,

$$N = \frac{m}{M} \times \text{Avogadro's number} = \frac{0.015 \times 6.023 \times 10^{23} \text{ atoms}}{90}$$

Activity of the sample,

$$R = \lambda / N = \frac{0.693}{T_{1/2}} N = \frac{0.693 \times 0.015 \times 6.023 \times 10^{23}}{28 \times 3.154 \times 10^7 \times 90}$$

$= 7.877 \times 10^{10}$ disintegration/sec $= 7.877 \times 10^{10}$ Bq

$$= \frac{7.877 \times 10^{10}}{3.7 \times 10^{10}} \text{Ci} = 2.13 \text{Ci}.$$

14. Calculate the compare the energy released by (a) fusion of 1.0 kg of hydrogen deep within Sun and (b) the fission of 1.0 kg of ^{235}U in a fission reactor.

Sol. (a) In the fusion reactions taking place within core of sun, 4 hydrogen nuclei combines to form a helium nucleus with the release of 26 MeV of energy.

$$4\,^1_1H \rightarrow \,^4_2He + 2e^+ + 26 \text{ MeV}$$

Number of atoms in 1 kg of ^1_1H

$$n = \frac{1000g \times 6 \times 10^{23}}{\text{Atomic mass}} = \frac{1000g}{1g} \times 6 \times 10^{23} = 6 \times 10^{26} = 6 \times 10^{26} \text{ atoms}$$

Energy released inthe fusion of 1 kg of ^1_1H

$$E = \frac{6 \times 10^{26} \times 26}{4} \text{MeV} = 39 \times 10^{26} \text{MeV}$$

(b) Energy released per fission of U-235 is 200 MeV.

Number of atoms in 1 kg $U = 235$

$$n = \frac{1000g \times 6 \times 10^{23}}{235g} = 25.53 \times 10^{23}$$

Total energy released for fission of 1 kg of uranium

$E = 25.33 \times 10^{23} \times 200$ MeV $= 5.1 \times 10^{26}$ MeV

So the energy released infusion of 1 kg of Hydrogen is nearly 8 times the energy released in fission of 1 kg of uranium-235.

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1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. The energy released during a nuclear reaction is called .... energy
2. The nuclear fuel in the sun is ....
3. U-238 has .... neutrons.
4. In a nuclear reactor, nuclear energy is converted into ....
5. If the binding energy per nucleon for $_3Li^7$ is 5.6 MeV, the total binding energy of a lithium nucleus is .... MeV.
6. In plants and animals, the ratio of C^{14} to C^{12} is ....
7. The radioactive radiation which can be stopped easily is ....
8. When an α-particle is ejected, the atomic number of the atom decreases by ....
9. The cathode rays emitted from a concave cathode meet at ....
10. Energy released in a nuclear reaction is given by ....
11. .... are used to absorb the neutrons in a nuclear reactor.
12. The first experiment on radioactivily was done with the element ....

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Atom bomb is based on the property of fission.
2. High energy neutrons are used in a nuclear reactor to initiate the fission reaction?
3. Cadmium rods are used as moderators in a nuclear reactor.
4. Higher the mass defect, higher will be the stability of the nucleus.
5. The e/m ratio of anode rays is constant irrespective of the gas filled inside the discharge tube.
6. Thorium series is also called 4n series.
7. Radioactive isotope of carbon is C^{14}
8. The radioactive isotope used in the treatment of cancer is a good source of γ rays radiations.
9. In all radioactive series, the end element formed is lead.
10. 4n + 2 series is called Uranium series.

Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in* ***column I*** *have to be matched with statements (p, q, r, s) in* ***column II.***

1. Column II give fission probability relative to U^{236} for nuclide given in column I match them correctly.

Column I	Column II
(A) U^{236}	(p) 0.001
(B) U^{239}	(q) 1
(C) Pu^{240}	(r) 1.5
(D) Am^{244}	(s) 0.0002

2. Match the following

Column I	Column II
(A) Coolidge tube	(p) present in all natural radioactive series
(B) α decay	(q) istones
(C) Radon	(r) decrease in atomic number by two
(D) $_{14}S^{31}$, $_{15}P^{32}$	(s) X-rays

3. Match the following.

Column I	Column II
(A) Binding energy per nucleon	(p) $E = mc^2$
(B.) Moderator	(q) to slow down
(C) Thermonuclear reaction	(r) nuclear fusion
(D) Mass energy equivalence	(s) Stability of nucleus

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VSAQ Very Short Answer Questions :

DIRECTIONS : *Give answer in one word or one sentence.*

1. In a discharge tube, at what pressure cathode rays are produced?
2. If the half-life period of a radioactive substance is 0.696 years, what is its decay constant?
3. What happens when cathode rays are suddenly stopped?
4. How can we say that cathode rays consist of negatively charged particles?
5. Define binding energy.
6. How are X-rays produced?
7. What forces are responsible for keeping the nucleons together in a nucleus?
8. Which rays among α, β and γ are deflected most in a magnetic field? Which rays remain undeflected?
9. What is a moderator? Give one example.
10. What is radioactive transformation or radioactive decay?
11. Name the three radioactive series. Which series is referred to as 4n Series?
12. What is a solar cell?
13. What are the advantages and disadvantages of a solar cell?
14. What energy transformation takes place in a solar cell?
15. What factors make a solar cell very expensive?
16. What is a solar panel?
17. Name the scientist who gave correct explanation of the source of sun's energy.
18. What is the surface temperature of the sun?
19. Name the fuel used in atomic reactors.
20. How much energy is released by one atomic mass unit of substance?
21. Name the process that forms the principle of a nuclear
    (i) atom bomb (ii) hydrogen bomb
22. Which of the two processes is carried out at a higher temperature: nuclear fission or nuclear fusion?
23. What do you understand by nuclear wastes?

SQA Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. Define nuclear fission and fusion reactions.
2. What are advantages and disadvantages of nuclear reactors?
3. Mention any three harmful effects of nuclear radiation on our body.
4. A tremendous amount of energy is released during a nuclear fission reaction. Why?
5. Give two applications of nuclear fission.
6. What would happen if all the hydrogen present in the sun is converted into helium?
7. It is said that the energy produced from nuclear fusion would create fewer pollution problems than the energy produced by nuclear fission. Explain why?
8. Cadmium rods play an important role in a nuclear reactor. What happens
   (i) when they are completely inserted into nuclear fuel and
   (ii) when they are slowly withdrawn from the nuclear fuel?
9. "Obtaining of energy from nuclear fusion reactions is preferable to obtaining of energy from nuclear fission reactions". Give two reasons to justify this statement.
10. What are radioactive isotopes? Mention two harmful effects of nuclear radiations.
11. What is nuclear fusion reaction? Why are such reaction not possible in the school laboratory? State the amount of energy released by one gram of hydrogen in the sun.
12. Name the process involved in the liberation of energy in (i) the sun and (ii) a nuclear reactor. Mention any two differences between the two processes.
13. Indicate in symbols for any three isotopes of uranium. Which one among these is used for nuclear fission ? What is meant by criticality of a nuclear reaction?
14. What is the cause of release of unusually large energies in nuclear fission reactions? How is the energy per fission calculated?

LAQ Long Answer Questions :

DIRECTIONS : *Give answer in four to five sentences.*

1. Name the main components of the nuclear reactor and describe their function.
2. Compare the energy during fission and fusion. What is the advantage of fusion over fission?
3. A radioactive sample is kept at the centre of a large evacuated sphere. How safe will it be?
4. Explain Bohr's atomic model.
5. Explain in detail the nuclear hazards and the safety precautions to be taken.
6. Describe how cathode rays are produced in a discharge tube. Write down the properties and uses of cathode rays.
7. Describe in detail the process of β-decay and γ-decay.
8. Compare the properties of α, β and γ radiations.

2 EXERCISE

MCQ Multiple Choice Questions

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. In a nuclear power plant, uranium atoms
(a) combine and give off heat energy
(b) split and give off heat energy
(c) burn and give off heat energy
(d) split and give off electrons

2. Solar energy is produced by the following reaction
(a) Fission reaction
(b) Fusion reaction
(c) Chemical reaction
(d) None of the above

3. The volume occupied by an atom is greater then the volume of the nucleus by a factor of about
(a) 10^1 (b) 10^5
(c) 10^{10} (d) 10^{15}

4. Which of the following is true for isotopes of specimen of U^{235} and U^{238}?
(a) both contain same number of neutrons
(b) both contain same of number of proton, electron and neutron
(c) both contain same number of proton and electron but U^{238} contains three more neutrons than U^{235}
(d) U^{238} contain three less neutrons than U^{235}

5. Atomic nucleus contains
(a) electron & photon
(b) electron, proton & neutron
(c) electron & neutron
(d) proton & neutron

6. The atomic number & mass number of element is Z & m then number of neutron will be .
(a) $m \times z$ (b) $m+z$
(c) m/z (d) $m-z$

7. Nuclei containing different number of protons but same number of neutrons are called
(a) Iso clinics (b) isobars
(c) isotones (d) isotopes

8. 1 amu is equivalent to
(a) 9.31 MeV (b) 931 KeV
(c) 93.1 MeV (d) 931 MeV

9. The dependence of density [d] of nuclear matter on the mass number A is
(a) $d \propto A$ (b) $d \propto \sqrt{A}$
(c) $d = \text{const.}$ (d) $d \propto 1/A$

10. The wrong statement is
(a) Nuclear forces are strongest
(b) Nuclear forces are very short range forces
(c) Nuclear force increase when the number of nucleons is increased
(d) Nuclear force is produced by the exchange of pions

11. Range of nuclear force is approximately
(a) 2×10^{-10} m (b) 1.5×10^{-20} m
(c) 7.2×10^{-4} m (d) 1.4×10^{-15} m

12. The mass number of a nucleus is equal to the number of
(a) Electron it contains (b) Protons it contains
(c) Neutrons it contains (d) Nucleons it contains

13. The neutron was discovered by
(a) Marie Curie (b) Pierre Curie
(c) James Chadwick (d) Rutherford

14. The order of magnitude of the density of nuclear matter is
(a) 10^4 kg/m^3 (b) 10^{17} kg/m^3
(c) 10^{27} kg/m^3 (d) 10^{34} kg/m^3

15. Force between protons in nucleus will be
(a) only nuclear (b) only coulomb
(c) nuclear & coulomb (d) coulomb & gravitational

16. The mass equivalent of 931 MeV energy is
(a) 1.66×10^{-27} kg (b) 6.02×10^{-24} kg
(c) 1.66×10^{-20} kg (d) 6.02×10^{-27} kg

17. Boron rods are used in nuclear reactor as
(a) moderator (b) control rods
(c) coolant (d) protective shield

18. Best moderator for neutron is
(a) berillium oxide (b) pure water
(c) heavy water (d) graphite

19. Nuclear fission was discovered by
(a) OttoHahn and strassman
(b) Fermi
(c) Bethe
(d) Rutherford

20. 200 MeV of energy may be obtained per fission of U^{235}. A reactor is generating 1000 kW of power. The rate of nuclear fission in the reactor is
(a) 1000 (b) 2×10^8
(c) 3.125×10^{16} (d) 931

21. In the process of nuclear fusion
(a) Only heavy nucleus break into light nuclei
(b) Fusion of light nuclei at normal temperature
(c) Fusion of light nuclei at high pressure and low temperature
(d) Fusion of light nuclei at high pressure and high temperature

22. When $_{92}U^{235}$ undergoes fission 0.1% of its original mass is changed into energy. How much energy is released if 1kg of $_{92}U^{235}$ undergoes fission
(a) 9×10^{10} J (b) 9×10^{11} J
(c) 9×10^{12} J (d) 9×10^{13} J

23. The cause of energy liberated in nuclear reaction is
(a) Change of potential energy into kinetic energy
(b) Kinetic energy of resultant nucleus
(c) Energy equivalent to mass lost
(d) None of these

24. Atom bomb consists of pieces of $_{92}U^{235}$ and a source of
(a) Proton (b) Neutron
(c) Meson (d) Electron

25. When four hydrogen nuclei fuse together to form helium nucleus, then in this process
(a) Energy is absorbed.
(b) Energy is liberated.
(c) Absorption and liberation of energy depends upon the temperature.
(d) Energy is neither liberated nor absorbed.

26. Two lighter nuclei are fused together to form a nucleus of medium atomic mass and energy is released in this process because
(a) Binding energy of lighter nuclei is more.
(b) Binding energy per nucleon of lighter nuclei is more.
(c) Binding energy per nucleon of medium nucleus is more.
(d) Energy is always released when two nuclei are fused.

27. Neutron ratio (available/used per fission in atomic reactor and atom bomb are
(a) $r > 1$ in atomic reactor and $r < 1$ in bomb.
(b) $r = 1$ in atomic reactor and $r > 1$ in bomb.
(c) $r > 1$ in both atomic reactor and bomb.
(d) $r < 1$ in both atomic reactor and bomb.

28. In atomic explosion, a temperature of about 10 million degrees is developed at the moment of explosion. The wavelength of light coming from the hot region of the atomic explosion lie in the region
(a) ultraviolet region (b) visible region
(c) infrared region (d) x-ray region

29. When light is incident on surface, photo electrons are emitted. For photoelectrons
(a) The value of kinetic energy is same
(b) Kinetic energy does not depend on the wave length of incident light
(c) The value of kinetic energy is equal to or less than a maximum energy
(d) None of the above

30. The phenomenon of photo electric emission depends on
(a) Only wave length of incident light
(b) Only work function of surface
(c) Only nature of surface
(d) All of the above

31. Photo electric effect is the phenomenon in which
(a) Photons come out of a metal when it is hit by a beam of electrons
(b) Photons come out of the nucleus of an atom under the action of an electric filed
(c) Electrons come out of metal with a constant velocity depending on frequency and intensity of incident light
(d) Electrons come out of a metal with different velocity not greater than a certain value which depends only on the frequency of the incident light wave and not on its intensity.

32. The electrons are emitted in the photo electric effect from a metal surface
(a) Only if the frequency of radiation is above a certain threshold value
(b) Only if the temperature of the surface is high
(c) At a rate that is independent of the nature of metal
(d) With a maximum velocity which is proportional to the frequency of incident radiation

33. Work function is
(a) Energy necessary to eject the electron from its orbit
(b) Energy necessary to eject the electron from metal
(c) Minimum necessary energy to eject the electron from metal
(d) Wavelength necessary for releasing an electron from a body

34. Einstein got noble prize for
(a) Photo electric effect (b) Compton effect
(c) Theory of relativity (d) None of the above

35. In a nuclear reactor, the moderator is
(a) uranium-234 (b) uranium-238
(c) cadmium (d) heavy water

36. Which of the following is a good nuclear fuel?
(a) uranium-236 (b) neptunium-239
(c) t horium-236 (d) plutonium-239

37. A radioactive substance has a half life of four months. Three fourth of the substance will decay in
(a) Three months (b) Four months
(c) Eight months (d) Twelve months

38. When hydrogen atom is in its first excited level, it's radius is
(a) Four times, it ground state radius
(b) Twice times, it ground state radius
(c) Same times, it ground state radius
(d) Half times, it ground state radius.

39. For a nuclear fusion process, suitable nucli are
(a) Any Nuclei
(b) Heavy Nuclei
(c) Light Nuclei
(d) Nuclei lying in the middle of periodic table

40. If N_0 is the original mass of the substance of half-life period $t_{1/2}$ = 5 years, then the amount of substance left after 15 years is
(a) $N_0/8$ (b) $N_0/16$
(c) $N_0/2$ (d) $N_0/4$

41. If mass-energy equivalence is taken into account, when water is cooled to form ice, the mass of water should
(a) increase
(b) remain unchanged
(c) decrease
(d) first increase then decrease

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42. Which of the following *cannot* be emitted by radioactive substances during their decay?
(a) Protons (b) Neutrinoes
(c) Helium nuclei (d) Electrons

MTOC More than One Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. 9.1×10^{-34} kg
(a) 0.51 MeV
(b) 9.1×10^{-28} gm
(c) 0.0005477 amu
(d) none of these

2. According to Bohr's theory of hydrogen atom, for the electron in the nth allowed orbit, the
(a) linear momentum is proportional to $(1/n)$
(b) radius is proportional to n
(c) the kinetic energy is proportional to $(1/n^2)$
(d) the angular momentum is proportional to n

3. An electron orbiting in a circular orbit around the nucleus of an atom
(a) has a magnetic dipole moment
(b) exerts an electric force on the nucleus equal to that on it by the nucleus
(c) does produces a magnetic induction at the nucleus
(d) has a net energy inversely proportional to its distance from the nucleus

4. A particular hydrogen like atom has its ground state binding energy 122.4 eV. Then
(a) its atomic number is 3
(b) an electron with 90 eV energy can interact with it and excite it
(c) an 80 eV electron emerges when an 80 eV electron interacts with it
(d) an electron of 8.2 eV and a photon of 91.8 eV are emitted when a 100 eV electron interacts with this atom

5. In which of the following situations the heavier of the two particles has smaller de Broglie wavelength? The two particles
(a) move with the same speed
(b) move with the same linear momentum
(c) move with the same kinetic energy
(d) have fallen through the same height

6. In the hydrogen atom in the ground state
(a) the kinetic energy of the electron is less than the potential energy which is positive
(b) the potential energy is less than the kinetic energy which is positive
(c) the potential energy is negative and the kinetic energy numerically less than the numerical value of potential energy
(d) the total energy is negative

7. Mark the correct options
(a) An atom with a vacancy has a smaller than the neutral atom
(b) K X-ray is emitted when a hole makes a jump from the K-shell to some other shell
(c) The wavelength of K X-ray is smaller than the wavelength of L X-ray of the same material
(d) The wavelength of K_α X-ray is smaller than the wave length of K_β X-ray of the same material

8. Who was/were won the novel prize of physics in 1903?
(a) Pierre Curie (b) Becquerel
(c) Rutherford (d) Madame Curie

9. When the nucleus of an electrically neutral atom undergoes a radioactive decay process, it will remain neutral after the decay if the process is
(a) an α-decay (b) a β-decay
(c) a γ-decay (d) a K-capture process

10. When a nucleus with atomic number Z and mass number A undergoes a radioactive decay process
(a) both Z and A will decrease if the process is α-decay
(b) Z will decrease but A will not change if the process is β^+ - decay
(c) Z will increase but A will not change, if the process is β^-- decay
(d) Z and A will remain unchanged if the process is γ - decay

11. During a β^-- decay which of the following statements are correct?
(a) The daughter nucleus has one proton less than the parent nucleus
(b) The daughter nucleus has one proton more than the parent nucleus
(c) An electron which is already present within the nucleus is rejected
(d) A neutron in the nucleus decays emitting an electron

12. The decay constant of a radioactive substance is 173 (years)$^{-1}$. Therefore
(a) nearly 63% of the radioactive substance will decay in 0.173 years
(b) half-life of the radioactive substance is (1/0.173) year
(c) one-fourth of the radioactive substance will be left after 8 years
(d) all the above statements are true

13. Which of the following reactions are not possible?
(a) $p \rightarrow n$ + positron + energy
(b) $n \rightarrow p$ + electron + energy
(c) ${}_{13}Al^{27} + {}_1Hl^2 \rightarrow {}_{12}Mg^{25} + {}_2He^4$
(d) ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{54}Xe^{140} + {}_{38}Sr^{95} + 2{}_0n^1 + \gamma$

14. The probability of disintegration per second of a nucleus in a given radioactive sample
(a) increases proportional to the life time lived by the nucleus
(b) decreases with the life time lived
(c) is independent of the life time lived
(d) depends on the total number of identical nuclei present in the sample

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15. The heavier nuclei tend to have larger *N/Z* ratio because
(a) a neutron is heavier than a proton
(b) a neutron is an unstable particle
(c) a neutron does not exert electric repulsion
(d) Coulomb force has longer range as compared to the nuclear force

16. $_{92}U^{235}$ is an alpha active nucleus. Then in a large quantity of the element
(a) the probability of a nucleus disintegrating during one second is lower in the first half-life and greater in the fifth half-life
(b) the probability of a nucleus disintegrating during one second remains constant for all the time
(c) quite an appreciable quantity of U^{235} will remain, even after average life
(d) the energy of emitted α-particle is less than the disintegration energy of the U^{235} nucleus

17. During the radioactive decay
(a) atomic mass number cannot increase
(b) atomic number may increase
(c) atomic number may decrease
(d) atomic number may remain unchanged

18. An electron in a hydrogen atom makes a transition $n_1 \rightarrow n_2$ where n_1 and n_2 are principle quantum numbers of the two state. Assume the Bohr model to be valid. The time period of the election in the initial state is eight times that in the final state. The possible values of n_1 and n_2 are
(a) $n_1 = 4, n_2 = 2$ (b) $n_1 = 8, n_2 = 2$
(c) $n_1 = 8, n_2 = 1$ (d) $n_1 = 6, n_2 = 3$

FIP Fill in the Passage :

DIRECTIONS : *Fill in the blanks in the following passage(s) from the words given inside the box.*

I.

release	chain reaction	produce	critical mass
fissions	isotopes	explosion	

Atomic Bomb, powerful explosive nuclear weapon fueled by the splitting, or fission, of the nuclei of specific ....1........ of uranium or plutonium in a ....2......... The strength of the ....3........ created by an atomic bomb is on the order of the strength of the explosion that would be created by thousands of tons of TNT (Trinitrotoluene).
An atomic bomb must provide enough mass of plutonium or uranium to reach ....4........, the mass at which the nuclear reactions going on inside the material can make up for the neutrons leaving the material through its outside surface. Usually the plutonium or uranium in a bomb is separated into parts so that critical mass is not reached until the bomb is set to explode. At that point, a set of chemical explosives or some other mechanism drives all the different pieces of uranium or plutonium together to ....5........ a critical mass. After this occurs, there are enough neutrons bouncing around in the material to create a chain reaction of........6.........
In the fission reactions, collisions between neutrons and uranium or plutonium atoms cause the atoms to split into pairs of nuclear fragments, releasing energy and more neutrons. Once the reactions begin, the neutrons ....7........ by each reaction hit other atoms and create more fission reactions until all the fissile material is exhausted or scattered.

II.

atom bomb	Fission	helium
temperature	Hydrogen bomb	hydrogen
harmful fusion		

Another form of nuclear energy is called fusion. Fusion means joining smaller nuclei to make a larger nucleus. The sun uses nuclear fusion of ....1......... atoms into ....2......... atoms. This gives off heat and light and other radiation. Also given off in this fusion reaction is energy.
Scientists have been working on controlling nuclear fusion for a long time, trying to make a fusion reactor to produce electricity. But they have been having trouble learning how to control the reaction in a contained space.
Controlled nuclear fusion is believed by many scientists to be the ultimate solution to the world's energy problems. The energy released in ....3......... reactions is many times greater than that released in ....4......... reactions. To date, however, the technology has not been developed to make use of this source of energy. What's better about nuclear fusion is that it creates less radioactive material than fission, and its supply of fuel can last longer than the sun

$$4\ {}_1H^1 \longrightarrow {}_2He^4 + 2\,{}_{+1}e^0 + 2v + Q$$

Fusion is possible at high pressure (~ 10^6 atom) and high temperature (~ 10^8 °C).
The proton-proton cycle happens at lower temperature as compared to carbon-nitrogen cycle.
Nuclear fusion in possible at a place which has reactants in large quantity.
........5......... works on principle of nuclear fusion.
The explosion of a hydrogen bomb needs an explosion of ....6......... to generate required ....7..........
No ....8......... radiations are produced in fusion.

PBQ Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

PASSAGE - 1

A physicist wishes to eject electrons by shining light on a metal surface. The light source emits light of wavelength of 450 nm. The table lists the only available metals and their work functions.

Metal	W_0 (eV)
Barium	2.5
Lithium	2.3
Tantalum	4.2
Tungsten	4.5

1. Which metal(s) can be used to produce electrons by the photoelectric effect from given source of light ?
(a) Barium only
(b) Barium or lithium
(c) Lithium, tantalum or tungsten
(d) Tungsten or tantalum

2. Which option correctly identifies the metal that will produce the most energetic electrons and their energies ?
(a) Lithium, 0.45 eV (b) Tungston, 1.75 eV
(c) Lithium, 2.30 eV (d) Tungston, 2.75 eV

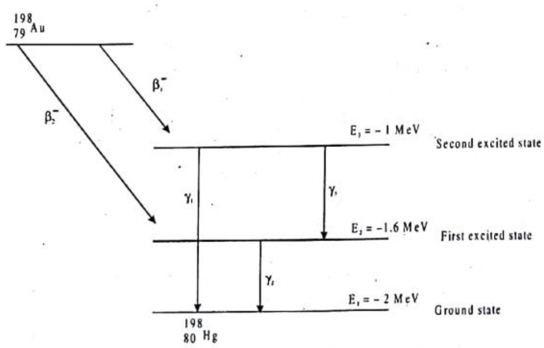
3. Suppose photoelectric experiment is done separately with these metals with light of wavelength 450 nm. The maximum magnitude of stopping potential amongst all the metals is-
(a) 2.75 volt (b) 4.5 volt
(c) 0.45 volt (d) 0.25 volt

PASSAGE - II

Gold nucleus ($_{79}Au^{198}$) can decay into mercury nucleus ($_{80}Hg^{198}$) by two decay schemes shown in figure. (i) it can emit a β particle (β_1) and come to ground state by either emitting one γ ray (γ_1) or emitting two γ rays (γ_3 & γ_4) (ii) it can emit one β particle (β_2) and come to ground state by emitting γ_2 ray.

Atomic masses : $^{198}Au = 197.9682$ amu ,

$^{198}Hg = 197.9662$ amu , 1 amu = 930 MeV/c². The energy levels of the nucleus are shown in figure.



1. What is the maximum kinetic energy of emitted β_2 particles–
(a) 1.44 MeV (b) 0.59 MeV
(c) 1.86 MeV (d) 1.46 MeV

2. What is the maximum kinetic energy of emitted β_1 particle is –
(a) 1.28 MeV (b) 0.77 MeV
(c) 1.86 MeV (d) 0.86 MeV

3. The wavelength of emitted γ rays are in the other –
(a) $\lambda_{\gamma_2} > \lambda_{\gamma_3} > \lambda_{\gamma_1}$ (b) $\lambda_{\gamma_3} > \lambda_{\gamma_2} > \lambda_{\gamma_1}$
(c) $\lambda_{\gamma_1} > \lambda_{\gamma_2} > \lambda_{\gamma_3}$ (d) $\lambda_{\gamma_3} = \lambda_{\gamma_2} = \lambda_{\gamma_1}$

A&R *Assertion & Reason :*

DIRECTIONS : *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect.**
(d) If **Assertion** is **incorrect** but **Reason** is **correct.**

1. **Assertion :** Nuclear forces are independent of charges.
Reason : Nuclear force is not a central force.

2. **Assertion :** The strength of photoelectric current depends upon the intensity of incident radiation.
Reason : A photon of energy E (= hν) possesses a mass equal to E/c² and momentum equal to E/c.

3. **Assertion :** Binding energy (or mass defect) of hydrogen nucleus is zero.
Reason : Hydrogen nucleus contain only one nucleon.

4. **Assertion :** U^{235} nucleus, by absorbing a slow neutron undergoes nuclear fission with the evolution of a significant quantity of heat
Reason : During nuclear fission a part of the original mass of U^{235} is lost and gets converted into heat.

5. **Assertion :** The rest mass energy of a nucleus is smaller than the rest mass energy of its constituent nucleons in free state.
Reason : Nucleons are bound together in a nucleus.

6. **Assertion :** In a decay process of a nucleus, the mass of products is less than that of the parent.
Reason : The rest mass energy of the products must be less than that of the parent.

7. **Assertion :** In street light circuits, photo-cells are used to switch on and off the lights automatically at dusk and dawn.
Reason : A photocell can convert a change in intensity of illumination into a change in photocurrent that can be used to control lighting system.

Multiple Matching Questions :

DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1. Match the processes in column I with their properties in Column II.

Column I	Column II
(A) Nuclear fission	(p) involves weak nuclear forces
(B) Nuclear fusion	(q) involves conversion of matter into energy
(C) β-decay	(r) atoms of higher atomic number are used
(D) Exothermic nuclear reaction	(s) atoms of lower atomic reaction number are used

2. Match the following columns

Column I	Column II
(A) Nuclear fusion	(p) Converts some matter into energy
(B) Nuclear fission	(q) Generally possible for nuclei with low atomic no.
(C) β-decay	(r) Generally possible for nuclei with higher atomic number
(D) Exothermic nuclear	(s) Essentially proceeds by weak nuclear forces

3. Match the entries of column I with the entries of column II.

Column I	Column II
(A) The sun	(p) Nuclear fission
(B) Nuclear reactor reaction	(q) Nuclear fusion
(C) Total binding energy in a process is increased	(r) Energy is released
(D) Total binding energy in a process is decreased	(s) Energy is absorbed

HOTS Subjective Questions :

DIRECTIONS : *Answer the following questions.*

1. Name any one element that is used in making solar cells. On what property of the element in this use based?
2. Write any two harmful radiations emitted by nuclear wastes.
3. Mention any two harmful effects of nuclear radiations on human body.
4. The mass number of elements A, B and C are 2, 180 and 235 respectively. Which one of them is suitable to make (a) an atom bomb and (b) a hydrogen bomb ? Name the process involved in each case.
5. 48 kJ of energy is produced in 60 seconds in a nuclear reactor. Find the number of fissions which would be taking place per second, if the energy released per fission is 3.2×10^{-11} J.
6. If 786 kJ of energy is produced per hour in a nuclear fission reactor, work out the number of fissions that would be taking place in it in 10 minutes, given that the energy released per fission is 3.2×10^{-11} J.
7. What is a nuclear reactor? What is a moderator? State the functions of moderator in a nuclear reactor. Name two substances used as moderators.
8. State the laws of radioactive emissions.
9. Find the binding energy per nucleon for a lithium nucleus $_3Li^7$. Take mass of $_3Li^7 = 7u$, mass of proton 1.007825 u and mass of neutron = 1.008665 u. Take 1 u = 931.5 MeV.
10. What are prompt fission and delayed fission reactions?
11. Mention the properties of cathode rays.
12. What is nuclear fusion? What are the conditions for a nuclear fusion reaction to take place?
13. Explain nuclear chain reactions.
14. Explain why the energy released during fusion cannot be used to produce electricity.
15. Mention the properties of X-rays.
16. What is a nuclear reactor? Name its different parts.
17. Give any three uses of radio-isotopes.
18. Explain nuclear fission by giving an example.
19. Using $E = mc^2$, find out the energy released, when 1 u of mass disappears.
    Take 1 u = 1.66×10^{-27} kg.
20. What is a radioactive series? How is it formed? Explain.

SOLUTIONS

Brief Explanations of Selected Questions

Exercise 1

FILL IN THE BLANKS :

1. nuclear
2. hydrogen
3. 146
4. electrical
5. 39.2
6. a constant, i.e., 10^{-12}
7. α – rays
8. 2
9. centre of curvature
10. $E = mc^2$
11. cadmium rods
12. radium

TRUE / FALSE

1. True 2. False 3. False 4. False
5. False 6. True 7. True 8. True
9. True 10. True

MATCH THE FOLLOWING :

1. (A) $\rightarrow$ q; (B) $\rightarrow$ p; (C) $\rightarrow$ r; (D) $\rightarrow$ s
2. (A) $\rightarrow$ s; (B) $\rightarrow$ r; (C) $\rightarrow$ p; (D) $\rightarrow$ q;
3. (A) $\rightarrow$ s; (B) $\rightarrow$ q; (C) $\rightarrow$ r; (D) $\rightarrow$ p;

VERY SHORT ANSWER QUESTIONS :

1. 0.01 mm of Hg.
2. $\lambda = \dfrac{0.693}{T}$
3. X-rays are produced.
4. Direction of deflection in electric and magnetic fields.
5. Energy that results from the loss of mass when nucleus is formed.
6. When cathode rays are suddenly stopped by a metal target.
7. Nuclear forces are responsible.
8. (i) β-rays (ii) γ- rays
9. Used to slow down neutrons. Heavy water.
10. Disintegration of an unstable nucleus resulting in the formation of another nucleus.
11. (i) Uranium series, actino-uranium series and thorium series.
    (ii) Thorium series.
17. Hans Bethe
18. 5500-6000°C
19. ${}_{92}U^{235}$
21. (i) Nuclear fission (ii) Nuclear fusion
22. Nuclear fusion
23. The discarded or unwanted materials of nuclear industry are all called nuclear wastes.

SHORT ANSWER QUESTIONS :

3. (i) Damages of tissues to chromosomes enhancing mutation.
   (ii) Initiation of unwanted cell division leading to cancerous growth.
   (iii) Conversion of molecules of living cells into chemically-reactive ions, which disrupt cell membranes resulting in serious illness.
4. In a nuclear reaction, the mass of the reactants is more than the mass of the products. Thus, the loss of mass in a nuclear reaction is converted into energy according to the mass-energy equivalence equation, $E = mc^2$.
5. (i) The energy emitted during nuclear fission can trapped for peaceful uses like the generation of electricity.
   (ii) It is used in warfare-for making atomic bombs which are produced by uncontrolled nuclear fission.
6. In case all the hydrogen present in the sun is converted into helium, the temperature and pressure inside the sun will decrease. As a result of this, the sun will collapse due to its own gravity. When the size of sun decreases, its interior temperature will again rise and hydrogen nuclei will get liberated from the helium nuclei.
7. The products obtained in nuclear fusion are not radioactive. Since they are not harmful, they can be disposed off easily. On the other hand, the products and by-products given out in nuclear fission are radioactive and hence are dangerous as they pollute water and air.
8. (i) All neutrons are absorbed, and the chain reaction stops.
   (ii) Correct number of neutrons are left behind to sustain the chain reaction and the reactor becomes critical.
9. (i) Nuclear fusion generates more energy than nuclear fission. (ii) The products formed in fusion reactions are non-radioactive and do not create radioactive pollutions.
10. Radioactive isotopes are those isotopes which release, spontaneously, α, β, γ radiations. The radiations cause, (i) Genetic disorder, (ii) Skin problems.
11. Nuclear fusion reaction is the reaction in which lighter nuclei combine to form heavier nucleus, with the release of large amount of energy. These reactions are not possible in school laboratory, since the energy released is quite high and difficult to handle.
    One gram of hydrogen releases 62,000,000,000 eV or 62×10^9 eV energy.
12. (i) Fusion of Hydrogen, (ii) Fission.
    Fission has been controlled and forms radioactive products and lighter elements. Fusion produces energy which is uncontrollable and heavier elements.
13. Isotopes of Uranium
    $${}^{235}_{92}U,\ {}^{238}_{92}U \text{ and } {}^{239}_{92}U.$$
    When sufficient ${}^{235}U$ is available to carry a chain, controlled reaction, the reactor is said to be in critical state.

14. The mass of nuclei obtained after the fission is less than the mass of the disintegrated nucleus. This difference in mass i.e., lost mass reappears in the form of large energy at a rate governed by the Einstein mass-energy relation.
To find energy per fission.
(i) Find the mass of reactants in kg or amu.
(ii) Find the mass of the nuclei obtained after fission in amu.
(iii) Find the difference in mass called mass defect (Δm).

LONG ANSWER QUESTIONS :

1. (i) A core [For nuclear fuel]
(ii) A moderator [For slowing down fast neutrons]
(iii) Control rods [To absorb (or remove) extra neutrons]
(iv) Coolant or heat exchanger [For transferring heat from the core]
(v) A Protective shield [To prevent harmful radiations from escaping to the surroundings]

Core: It contains nuclear fuel, which undergoes nuclear fission very rapidly to generate energy. Fuels commonly used in nuclear reactors are uranium-235 (U-235) and plutonium-239 (Pu-239).

Nuclear fuel: The nuclear fuel used in nuclear reactors is usually enriched ^{235}U (3%) or ^{239}Pu. The fuel is sealed in aluminium cylinders, called fuel rods.

Moderator: The neutrons released are fast neutrons having energy of about 1 MeV. These neutrons are slowed down to energy of 0.025 eV (thermal neutron) by using substances rich in protons. These substances are called moderators. The commonly used moderators are heavy water (D_2O) and graphite.

Control rods: The rate of reaction is controlled by inserting or withdrawing rods made of elements whose nuclei absorb neutrons without undergoing fission. These rods are called control rods. Typical examples of control rods are those made of boron or cadmium.

Coolant: The purpose of the coolant is to carry the energy of the fission reaction from the core of the reactor and take it to a place of utilisation; i.e., a steam generator. The commonly used coolants are heavy water, molten sodium, molten potassium and pressurised CO_2

Protective shield: To stop the spreading of the harmful radiations from a nuclear reactor, the reactor is enclosed in thick concrete walls, often 10 m in thickness.

2. The energy given out during fusion is about seven times the energy given out during fission for the same mass. The advantage of the fusion reaction over the fission reaction is that the energy produced by fusion is clean and is not accompanied by the generation of any hazardous radioactive waste. Nuclear Fusion also has the following advantages over nuclear fission
(i) For the same masses of the reacting substances involved, fusion releases much more energy than fission.
(ii) The products of fusion reaction are not radioactive and are, therefore, easier to dispose off as compared to the products formed by fission reaction.
(iii) Nuclear fission requires uranium as a fuel which is limited and exhaustible substance, while nuclear fusion requires deuterium which can be obtained abundantly from sea water.

3. For safety, the radiations (α, β and γ) emitted by the radioactive sample should not come out of the sphere. α-particles have least penetrating power than all other radiations therefore, the walls of the sphere easily stops them. β-particles will not be stopped by the walls and there will be no absorption of β-particles inside the sphere as the air has been withdrawn from it. Some safety is obtained if the sphere is large because beta particles reaching out of the sphere will depend upon the radius of the sphere. γ-radiations are also not absorbed by the walls. Thus, for safety, the container should have lead walls and it should not be evacuated. The air will help in absorbing the radiations.

Exercise 2

MULTIPLE CHOICE QUESTIONS :

1.	(b)	2.	(b)	3.	(c)	4.	(c)	5.	(d)
6.	(d)	7.	(c)	8.	(d)	9.	(c)	10.	(c)
11.	(d)	12.	(d)	13.	(c)	14.	(b)	15.	(c)
16.	(a)	17.	(b)	18.	(c)	19.	(a)	20.	(c)
21.	(d)	22.	(a)	23.	(c)	24.	(b)	25.	(b)
26.	(c)	27.	(b)	28.	(d)	29.	(c)	30.	(d)
31.	(c)	32.	(a)	33.	(c)	34.	(a)	35.	(d)
36.	(d)								

37. (c) Substance left undecayed - $N_0 - \frac{3}{4}N_0 = \frac{1}{4}N_0$

$$\frac{N}{N_0} = \frac{1}{4} = \left(\frac{1}{2}\right)^n$$

$\therefore$ n = 2 i.e. in two half lives
$\therefore$ $t = nT = 2 \times 4 = 8$ months

38. (a) $r_n = r_o.n^2$, where r_o is radius of G-state & r_n is radius of n^{th} state. (For first excited state n = 2).
39. (c)
40. (a) Amount left = $N_0/2^n = N_0/8$ (Here n = 15/5 = 3)
41. (a) Because thermal energy decreases, therefore mass should increase.
42. (a)

MORE THAN ONE CORRECT :

1.	(b, c)	2.	(a, c, d)	3.	(a, b, c, d)
4.	(a, c, d)	5.	(a, c, d)	6.	(c, d)
7.	(b, c)	8.	(a, b)	9.	(c, d)
10.	(a, b, c, d)	11.	(b, d)	12.	(a, c)
13.	(a, d)	14.	(c, d)	15.	(c, d)
16.	(b, c, d)	17.	(a, b, c, d)	18.	(a, d)

FILL IN THE PASSAGE :

I. 1. isotopes; 2. chain reaction; 3. explosion; 4. critical mass; 5. produce; 6. fissions; 7. release

II. 1. hydrogen; 2. helium; 3. fusion; 4. Fission; 5. Hydrogen bomb; 6. atom bomb; 7. temperature; 8. harmful

PASSAGE BASED QUESTIONS :

Passag e-I

1. (b) $DE = \frac{12400}{4500Å}$
$\Delta = 2.75\,eV$
For photoelectric effect, $\Delta E > W_0$ (work function).

2. (a) $\Delta E = W_0 + E$; $(E_k) = \Delta E - W_0$
For maximum value of (E_k), W_0 should be minimum
W_0 for lithium = 2.3 eV
$\therefore (E_k) = 2.75 - 2.3 = 0.45\,eV$

3. (c) The maximum magnitude of stopping potential will be for metal of least work function.
$\therefore$ required stopping potential is
$V_s = \frac{hv - \phi_0}{e} = 0.45$ volt.

Passage-II

1. (d) Total energy released from $Au^{198} \to Hg^{198}$ in ground state $= (\Delta m_{loss})\,c^2 = (197.9682 - 197.9662)(930) = 1.86$ MeV
Energy released from ^{198}Hg in first excited state $\to$ Hg in ground state $= (-1.6) - (-2)$ MeV $= 0.4$ MeV
$\Rightarrow$ Energy released from $Ag^{198} \to Hg^{198}$ second excited state $= 1.86 - 0.4 = 1.46$ MeV = max K.E. of β_2 particle.

2. (d) Similarly maximum kinetic energy of β_1 particle $= 1.86 - 1 = 0.86$ MeV

3. (a)

ASSERTION & REASON :

1. (b) 2. (b) 3. (a) 4. (a) 5. (a)
6. (a) 7. (a)

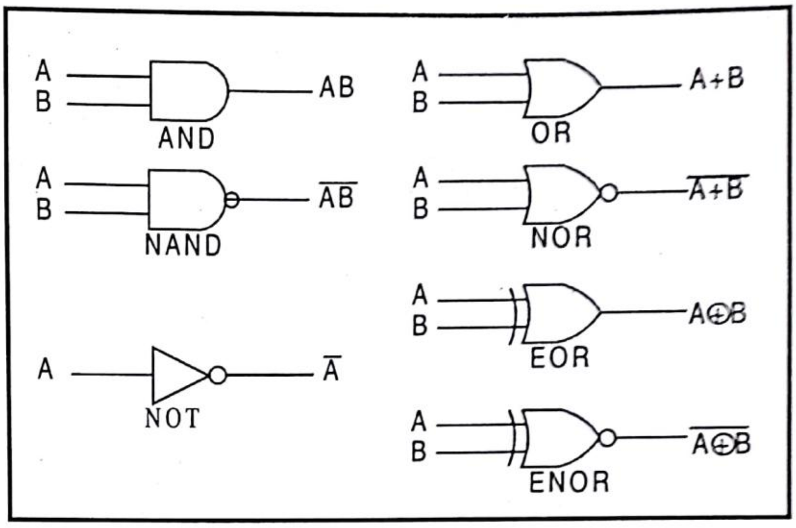
MULTIPLE MATCHING QUESTIONS :

1. (A) $\to$ q, r; (B) $\to$ q, s; (C) $\to$ p; (D) $\to$ q
2. (A) $\to$ p, q; (B) $\to$ p, r; (C) $\to$ s, p; (D) $\to$ p, q, r
3. (A) $\to$ q, r; (B) $\to$ p, r; (C) $\to$ r; (D) $\to$ s

HOTS SUBJECTIVE QUESTIONS :

1. Germanium or Silicon. The use is based on the semi-conducting property.
2. α, β and γ rays. (Any two)
3. (i) Genetical disorders (ii) Skin cancer.
4. (a) Atom bomb $\to$ Element C with Mass number 235 $\to$ nuclear fission.
(b) Hydrogen bomb $\to$ Element A with Mass number 2 $\to$ nuclear fusion.
5. Energy = 48000 J, Time = 60 seconds.
Energy per fission $= 3.2 \times 10^{-11}$ J
Number of fissions $= \frac{48000}{60 \times 3.2 \times 10^{-11}} = 250 \times 10^{11}$
6. Energy released per hour = 786 kJ,
Energy released in 10 minutes $= \frac{786 \times 10}{60} = 128$ kJ
$= \frac{\text{Total energy released}}{\text{Energy released perfission}} = \frac{128 \times 1000\,J}{3.2 \times 10^{-11}\,J}$
$= 40 \times 10^{14} = 4 \times 10^{15}$ fissions.
7. Nuclear reactor is a device where a nuclear fission reaction is carried out to generate electricity. Moderators are substances which slow down the neutrons and make them fit enough to induce fission in ^{235}U nuclei. Heavy water and Graphite act as moderators.
8. $N = N_0 e^{-\lambda t}$,
Where N_0 and N are the number of atoms of the substance at t = 0 and 't' respectively λ-disintegration constant.
9. (i) Mass defect $= [3 \times m_p + 4 \times m_n] - 7u$
(ii) Binding energy = mass defect × 931.5 MeV
(iii) Binding energy per nucleon $= \frac{\text{Binding energy}}{7}$
10. (i) Fission takes place as soon as the heavy nucleus is bombarded with a neutron.
(ii) Neutron enters a heavy nucleus causing instability and eventually leading to the fission.
11. (i) Travel in straight line.
(ii) Exert mechanical force on the objects.
(iii) Deflect in presence of electric and magnetic fields.
(iv) Ionize the gas through which they pass.
(v) Affect photographic plates.
12. (i) Two or more lighter nuclei combine to give a heavy nucleus.
(ii) High temperature.
13. (i) A series of nuclear fissions where by the neutrons produced in each fission cause additional fission, releasing enormous amount of energy.
14. (i) fusion reactions are not chain reactions – Not possible to sustain the reaction
(ii) Requires a high temperature for nuclear reaction to take place.
(iii) Difficult to harness and convert the heat energy produced into mechanical energy.
15. (i) Electromagnetic radiations.
(ii) Wavelength is of the order of 1 A°
(iii) Affect photographic plates
(iv) Travel with velocity of light in straight line
(v) Produce fluorescence in certain materials.
(vi) Not affected by electric and magnetic fields.
16. (i) A device, in which a self-sustaining controlled chain reaction is produced in a fissionable material.
(ii) Nuclear fuel, moderator, coolant, shield, control rods.
17. (i) $_{11}Na^{24}$ – To detect a clot in the blood in the human body.
(ii) $_{27}Co^{60}$ – To kill cancer cells.
(iii) $_{53}I^{131}$ – To test the functioning of the thyroid gland.
18. (i) A process in which a heavy nucleus of a radioactive substance like uranium is split into lighter nuclei by the bombardment of a low energy neutrons.
(ii) $_{92}U^{235} + {_0}n^1 \longrightarrow {_{36}}Kr^{92} + {_{56}}Ba^{141} + 3\,{_0}n^1 + \text{energy}$
19. $E = \Delta mc^2$
20. (i) Sequential decay of a radioactive nucleus.
(ii) Results in the production of new nuclei at each stage.
(iii) Gives rise to a series of elements called radioactive decay series.

chapter 10



ELECTRONICS

Introduction

We watch T.V. in our houses for entertainment, news, sports live etc. We use computers for multi-purposes. We use calculators, electronic watches, digital thermometers, digital glucometers to measure the amount of glucose in our body and so on. There are a number of devices which we use in our day to day life which are based on the subject matter of this chapter. The chapter is all about the branch of physics called electronics. There is no wonder to say that we are living in the age of electronics. It is prevailing in every walk of our life. The most powerful discovery of this branch of physics is the mobile technology which has become an inevitable part of our life. This chapter deals with the components of electronics such as semiconductors, diodes, *p-n* junction, transistor, the logic gates etc.

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ENERGY BANDS IN SOLIDS

In an isolated atom, electrons present in energy level but in solid, atoms are not isolated. There is interaction among each other. Due to this, energy level split into different energy levels. Quantity of these different energy levels depends on the quantity of interacting atoms. Splitting of sharp and closely compact energy levels result into energy band. This is discrete in nature.
Let use see the energy bands in sodium.
When the sodium atoms are far apart, all 3s electrons have same energy and as we begin to move them together, the energy levels begin to "split". The situation for four sodium atoms is shown in figure. As the number of atoms is increased (may be 10^{20} atoms), the levels become so numerous and so close that we can no longer distinguish the individual levels as shown in figure. We can regard the N atoms as forming an almost continuous band of energy. Since, those levels were identified with 3s atomic levels of sodium, we refer to the 3s band.

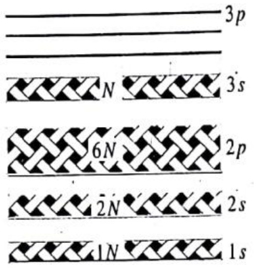

Fig. 10.1- *Energy bands in sodium metal (G state)*

Each band has a total of N individual levels. Each level can hold $2 \times (2\ell + 1)$ electrons (ℓ is azimuthal Quantum number), so the capacity of each band is $2(2\ell + 1)N$ electrons.
Figure shows a complete representation of energy bands in sodium metal. The $1s$, $2s$ and $2p$ bands are each full, $3s$ band is half and $3p$ band is completely empty. The 1s and $2s$ bands each contain $2N$ electrons and $2p$ band contain $6N$ electrons. The $3s$ band contain N electron, so it is half filled. The band, which can hold $6N$ electrons is completely empty.
When we add energy to a system i.e., to sodium metal, the electron can move from filled state to empty state. In this case, the electron can move from partially full states of $3s$ band to empty states of $3s$ band by absorbing small amount of energy or move to $3p$ band by absorbing larger amount of energy.
In a solid at zero temperature, the electron settle into the available states of lowest energy. The lower energy bands will therefore be completely filled and the upper most energy band will be either filled or partially filled, depending on the number of electrons & on the number of available states. The diffence between conductor and insulator arises from a partially filled or a completely filled upper most energy band.

CONDUCTORS : A conductor such as sodium, has a partially filled band (in sodium, the upper most band 3s is half filled). In these substance, electrons are free to move by applying an electric field, because un-occupied states are available in upper most band (as in sodium in $3s$ band only half states are completely filled and half-states are empty or un-occupied). Therefore, these electrons are mobile and can contribute to electrical & thermal conductivity. For example the energy bands of sodium metal are shown in figure. In an isolated sodium atom, the six $3p$ lowest excited state for valence electrons are about 2.1 eV above two $3s$ G-states. But in solid sodium the $3s$ and $3p$ bands are spread out enough so that they actually overlap, forming a single band.

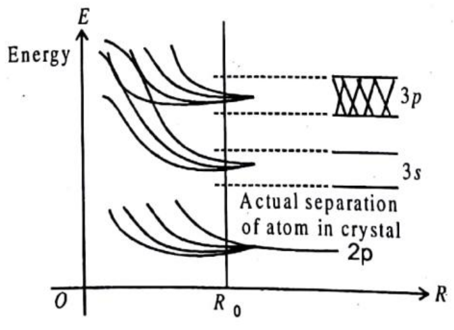

Fig.10.2 *Origin of energy bands in sodium metals, as atoms move together the energy level spreads into bands*

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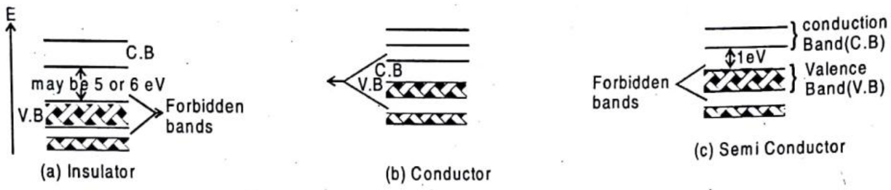

(For Si gap = 1.1 eV, For Ge gap = 0.7 eV)

Fig. 10.3: *Three types of energy band structure*

(a) **An insulator at absolute zero. A completely full valence band (V.B) is separated by a gap of several electron volt (may be 5 or 6 eV)from a completely empty conduction band (C.B) and electrons in the V.B can not move. At finite temperature, few electrons can reach upper band.**

(b) **A conductor at any temperature. There is a partially filled valence band and electrons are free to move in unoccupied states of valence band (may be called conduction band) when an electric field is applied.**

(c) **A semiconductor at T = 0. A completely filled V.B is separated by a smaller gap of 1eV or so from an empty conduction band. At finite temperatures, substantial numbers of electron can reach the C.B, where they are free to move.**

Because each sodium atom has only one valence electron but eight 3s and 3p states, that single band is only 1/8 filled and other states are unoccupied.

INSULATORS

In these substances (such as diamond), the upper most level is compeletely filled i.e., no unoccupied state is available for electron to move. The nearest unoccupied states are in next band (called C.B), but this is separated from filled band (called V.B) by an energy gap of about 6eV [shown in figure (a)]. Hence, electron in diamond refuses to carry an electric current.

SEMICONDUCTOR

A semiconductor, has a completely filled valence band i.e., it resembles an insulator at zero temperature. However, the gap between this filled valence band and next band (C.B) is small, about 1eV or less [shown in figure 10.3 (b)]. Hence, electrons can easily make the transitions from one band to another at room temperature and then carry an electric current (Silicon, Germanium are semiconductors). There are two types of semiconductor.

(i) Intrinsic Semiconductor : These semiconductors are pure materials in which the thermal vibrations of the lattice have liberated charge carriers (i.e., electrons & holes). In intrinsic semiconductor, the number of electrons are equal to the number of holes.

(ii) Extrinsic Semiconductor : They are impure semiconductors in which minutes traces of impurity introduces mobile charge carriers [which may be +ive (holes) or–ive (electrons)] in addition to those liberated by thermal vibration. Again there are two types of Extrinsic semiconductors.

N- type semiconductor

When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb, Bi) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donor impurity (N_D). Here free e^- increases very much so it is called as *n*-type semiconductor. Here impurity ions known as "Immobile Donor positive Ion". Free e^- called as majority charge carriers and holes called as minority charge carriers.

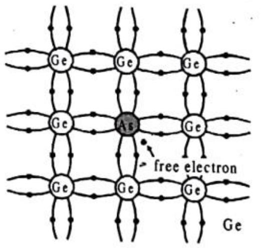

Fig.10.4

P -type semiconductor

When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In, Ga) then outer most three electrons of the valence band of impurity take part, in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded e^- from valance band are called as Acceptor impurity (N_A). Here holes increases very much so it is called as *p*-type semiconductor here impurity ions known as "Immobile Acceptor negative Ion". Free e^- are called as minority charge carries and holes are called as majority charge carriers.

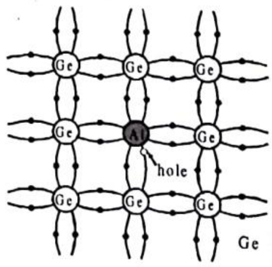

Fig.10.5

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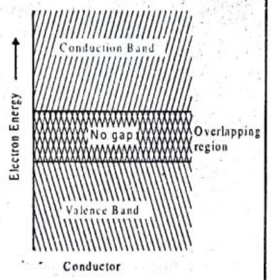
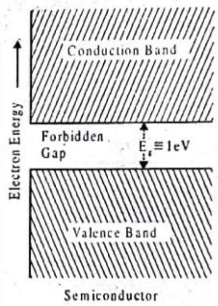
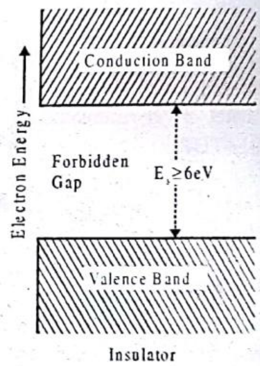
Knowledge ENHANCER

Comparison between conductor, semiconductor and insulator :

Properties	Conductor	Semiconductor	Insulator
Resistivity	$10^{-6} - 10^{-8}\ \Omega m$	$10^{-4} - 0.5\ \Omega m$	$10^{7} - 10^{16}\ \Omega m$
Conductivity	$10^{-6} - 10^{-8}$ mho/m	$10^{4} - 0.5$ mho/m	$10^{-7} - 10^{-16}$ mho/m
Temp. Coefficient of resistance (α)	Positive	Negative	Negative
Current	Due to free electrons	Due to electrons and holes	No current
Energy band diagram			
Forbidden energy gap	$\cong$ 0eV	$\cong 0 - eV$	$\geq$6eV
Example	Pt, Al, Cu, Ag	Ge, Si, C, GaAs GaF_2	Wood, plastic Diamond, Mica

PRINCIPLE OF THE p-n JUCTION DIODE

If we join a piece of *n*-type to a piece of *p*-type material by appropriate method, then we obtain *p-n* junction diode. It is clear that *p*-type has more hole concentration but less concentration of electrons than *n*-type semiconductor.

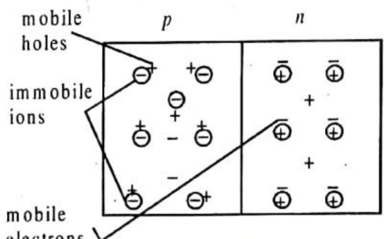


Fig 10.6 : Diffusion current

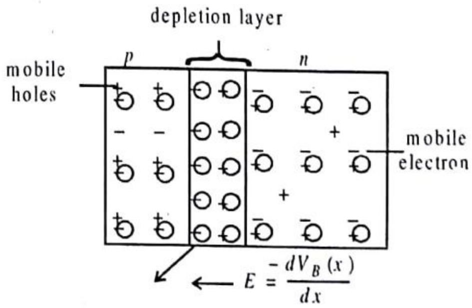


Fig 10.7 : Fixed ion or immobile charge carriers

Due to this difference in concentration, density gradient is established across the junction resulting in majority carriers diffusion: Holes diffuses (+ive ions) from *p*-type to *n*-type and electrons (–ive ions) from *n*-type to *p*-type (shown in figure) and terminating their existence by recombination.

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Important terms in *p-n* junction :

(i) Diffusion Current : We know that due to concentration difference, holes diffuse from *p*-side to *n*-side (in figure - 1(a)) they move from left to right) and electron diffuse from *n*-side to *p*-side (in figure (a) they move from right to left). But electric field at junction repels the holes as they come to depletion layer and only those holes which have high kinetic energy are able to cross the potential barrier. Similarly, electric field at junction repels electrons and those having high kinetic energy cross the junction. The electric potential of *n*-side is more +ive (or higher) than *p*-side –ive (lower). The variation of V_B is shown in figure (c). So diffusion results in an electric current from *p*-side to *n*-side known as diffusion current.

(ii) Drift Current : Due to thermal collision, some times a covalent bond is broken and electron-hole pair is created. But those electron-hole pairs are destroyed easily due to recombination. This process [generation of electron-hole (e-h) pair] occurs in the whole part of material.

But, if e-h pair is created in depletion region, the electron is quickly pushed by electric field towards *n*-side and holes towards p-side. As e-h pairs are continuously created in depletion region, there is a regular flow of electron towards *n*-side and holes towards *p*-side and so current flows from *n*-side to *p*-side. This current is drift current.

In steady state the magnitude of drift current is equal to diffusion current & since they are in opposite direction, hence there is no net transfer of charge at any cross-section.

This recombination produces narrow region near junction called depletion layer. Since, this region is depleted of free or mobile charge carrier and contains only immobile charge carriers, hence it is called depletion region. Due to these immobile charge carriers, a potential barrier V_B is established and further diffusion is stopped and equilibrium is reached (shown by figure). The sign of V_B is +ive towards the *n*-type and –ive towards *p*-type. The schematic symbol of diode and corresponding equivalance in terms of V_B are shown below in figure 10.8 (a) and (b).

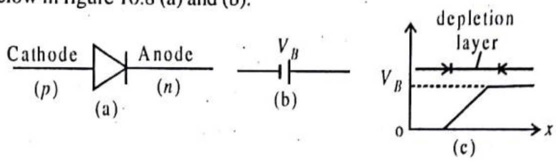

Fig 10.8

In figure (a) the triangle shows the direction of current. For Si diode the value of V_B is 0.7V and for Ge diode the value of V_B is 0.3V.

Forward bias : When *p*-side of the *p-n* junction is connected to the +ve terminal of a battery and n to –ve terminal, conduction takes place and the diode is said to be forward biased.

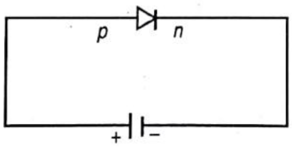

Fig. 10.9

Reverse bias : When *p*-side of he *p-n* junction is connected to the –ve terminal of a battery and *n*-side to the +ve., there is no conduction and diode is said to be reverse biased.

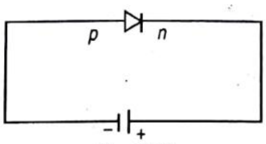

Fig. 10.10

Effect of biasing :

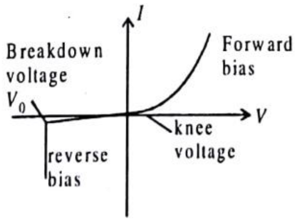

Fig 10.11

In forward bias, the thickness of depletion layer decreases (and potential barrier height also reduces), while in reverse bias, the thickness of depletion layer increases and potential barrier also increases). In forward bias the current increases exponentially and in reverse bias, the current remains constant at very small magnitude upto break down voltage V_0 and after that it increases sharply without any further increase of reverse voltage (shown by figure). The effect of forward biasing and reverse biasing on potential barrier are shown in figure.

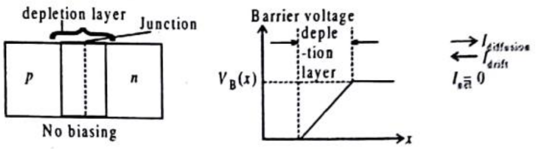

Fig.10.12 (a) : p-n junction without biasing

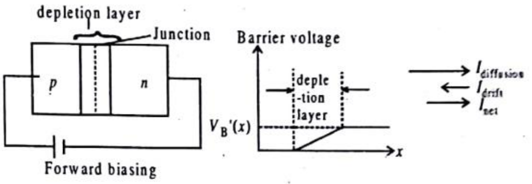

Fig.10.12 (b) : p-n junction with forward biasing

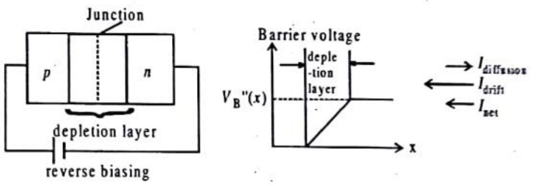

Fig.10.12 (c) : p-n junction with reverse biasing

RECTIFIER

Junction diode (*p-n* junction) can be used to convert the alternating current (a.c.) into direct current (d.c.). The process of conversion from a.c. to d.c. is known as rectification and the device is called rectifier. A *p-n* junction can be used as a helf wave or full wave rectifier.

Half wave rectifier

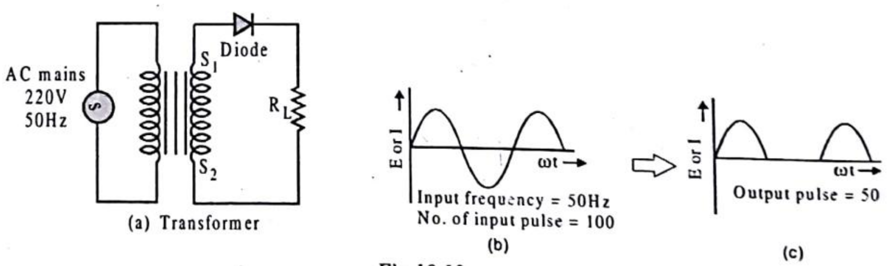

Fig.10.13

During the first half (positive) of the input signal. Let S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained.
During the second half (negative) of the input signal, S_1 and S_2 would be negative and positive respectively. The PN junction diode will be reversed biased. In this case, practically no current would flow through the load resistance. So, there will be no output voltage.
Thus, corresponding to an alternating input signal, we get a unidirectional pulsating output.

Peak voltage (PIV) $V_s = V_{in}$

In half wave rectifier PIV = maximum voltage across secondary coil of transformer.

Full wave rectifier : When the diode rectifies the whole of the AC wave, it is called full wave rectifier. Figure shows the experimental arrangement for using diode as full wave rectifier. The alternating signal is fed to the primary a transformer. The output signal appears across the load resistance R_L.

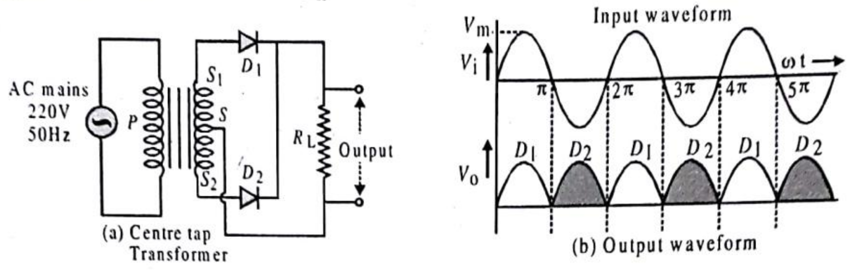

Fig.10.14

During the positive half of the input signal :
Let S_1 positive and S_2 negative.
In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.
During the negative half of the input signal :
Now S_1 is negative and S_2 is positive. So D_1 is reverse-biased and D_2 is forward biased. So only D_2 conducts and hence the current flows through the load resistance R_L from A to B.
It is clear that whether the input signal is positive or negative, the current always flows through the load resistance in the same direction and full wave rectification is obtained.

TRANSISTOR

Transistors are three terminal (solid state) devices just like triode. It can be assumed to consist of two back to back *p-n* junctions. In practice a junction transistor (*p-n-p*) consists of silicon (or germanium) bar crystal in which a layer of *n*-type silicon (or Ge) is sandwiched between two layers of *p*-type silicon and we get *p-n-p* transistor. Alternatively, it may consist of a layer of *p*-type between two layers of *n*-type material and we get a *n-p-n* transister as shown by figure.

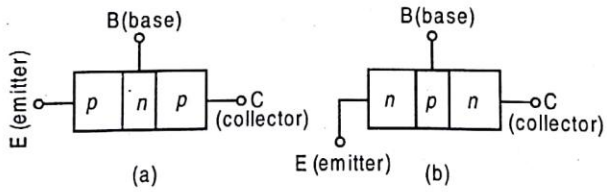

Fig.10.15

(a) **Components of transistor :**
Emitter (E) : It supplies charge carriers (electron in *n-p-n* transistor and holes in *p-n-p* transistor) and it has high density of impurity concentration i.e., highly doped. It is always forward biased.
Collector (C) : It is a region on other side of base. It has maximum area out of other sections (emitter and base) of transistor to dissipate the heat. It collects the charge carriers and it is always reverse biased.
Base (B) : It is middle region which forms the two junctions between emitter and collector. It is very lightly doped.
The schematic symbols of transistor are :

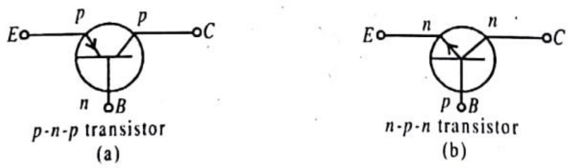

Fig.10.16

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(b) **Biasing of Transistor :** In proper biasing of transistor the input (i.e., base emitter junction) is always forward biased and output (i.e., collector base junction) is always reverse biased as shown in figure. [This scheme of biasing is same for all three transistor configurations; common base configuration (C.B), common emitter configuration (C.B) and common collector configuration (C.C)]

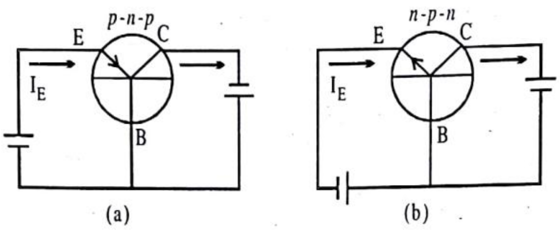

Fig.10.17

(c) **Working of Transistor :** Figure shows a common base configuration of *p-n-p* transistor. The forward biasing of emitter junction lowers the emitter base potential barrier height, whereas the reverse biasing of collector junction increases the collector-base potential barrier height. Hence, holes (majority carriers in *p*-type) flows through emitter to base and constitutes an emitter current I_E. Since, emitter is heavily doped in comparison to base, so approximately (only 5% holes recombine with electrons in base region and constitute base current I_B) 95% holes reach to collector and constitute collector current I_C. From Kirchoff's current Law,

$$I_E = I_C + I_B \qquad ...(1)$$

Equation. (1) holds true regardless of circuit configuration or transistor type (*p-n-p* or *n-p-n*) that is used.
The current gain of transistor is defined as ratio of collector current I_C to base current I_B i.e.,

$$\beta = \frac{I_c}{I_B} \qquad ...(2)$$

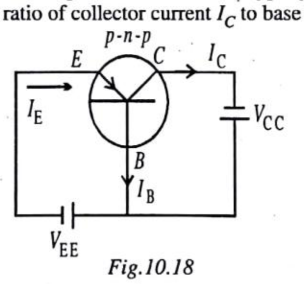

Fig.10.18

The value of β lies between 10 and100.

Since $I_E \approx I_C$ and exactly

$$I_E = \alpha I_C \qquad ...(3)$$

Whereas α is defined as the ratio of collector current I_C to emitter current I_E. The value of α is always less than unity. In terms of β, α is

$$\alpha = \frac{\beta}{1+\beta} \Rightarrow \beta = \frac{\alpha}{1-\alpha} \qquad ...(4)$$

(d) **Transistor Configuration :** There are three type of transistor configuration. We can take either terminal as input terminal and other terminal as output.

(i) **Common Base Configuration (C.B) :** Here base terminal is common to both input and output terminals. The emitter terminal is taken as input.

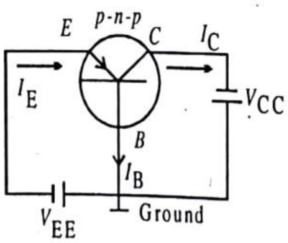

Fig.10.19

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(ii) **Common Emitter Configuration (C.E) :** Here emitter terminal is common to both input and output terminal as shown in. The base terminal is taken as input and collector is taken as output.

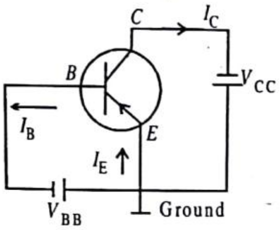

Fig.10.20

(iii) **Common Collector Configuration (C.C) :** Here the collector terminal is common to both input as well as output terminals as shown in figure. The base terminal is input & Emitter is output terminal.

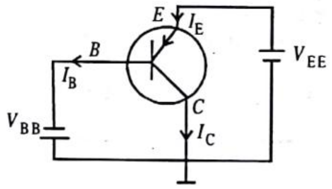

Fig.10.21

(e) **Transistor as an Amplifier :** Amplification is the process of linearly increasing the amplitude of a signal and is one of the major properties of a transistor.

This amplifing action was produced by transfering a current from a low (base emitter loop in forward biased and hence, provide low resistance path and collector base junction is reverse biased and hence gives high resistance path in common emitter configuration) to a high resistance circuit. The combination of two terms in italics results in label transists that is:

transfer + resistor → transistor

Common- Emitter Amplifier : Figure. 10.22, shows a basic common-emitter amplifier circuit in which we connect a signal source V_s. The input voltage loop is V_s, then from base to emitter through transister to ground (common refrence point) & then through V_{BE} back to V_s. The output voltage loop consists ground, then from emitter to collector through R_C. The emitter is connected to ground. During a +ive half- cycle of V_s, the forward bias across the emitter base junction will be increased, while during – ive half-cycle of V_s (signal source), the forward bias across emitter base junction will be decreased. Hence,

more electrons flow during +ive half-cycle and so we obtain more collector current and so large voltage drop across R_C and less value and V_{CE}. In negative half-cycle collector current decreases.

In the absence of input signal v_s, a D.C collector current I_C flows in collector circuit due to forward biased battery V_{BE}. This is called zero signal collector current. So total collector current is

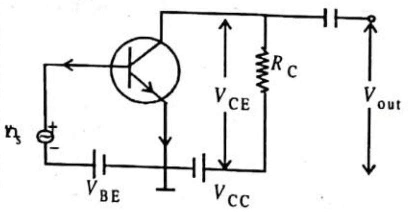

Fig. 10.22

$$I_{\text{total collector current}} = \underset{\text{d.c. collector current}}{I_C} + \underset{\text{a.c. collector current}}{I_c}$$

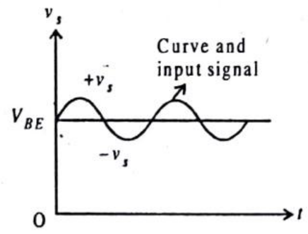

Fig. 10.23 (a) input signal superimposed on V_{BE}

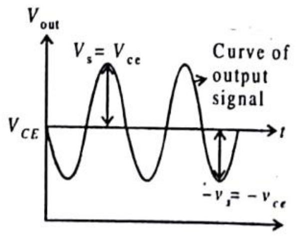

Fig. 10.23 (b) output amplifying signal wave form super imposed on V_{CE}

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The voltage from the collector to ground determines the output signal. When I_C (during +ive half cycle) increases, V_{CE} decreases and when I_C decreases (during – ive half-cycle) V_{CE} increase. So output voltage is 180° out of phase with input signal in *C.E* amplifier :

The current gain A_i is defined as ,

$$A_i = \frac{\Delta I_C}{\Delta I_B} = \frac{\text{change in load current/collector current}}{\text{change in input current/base current}}$$

The voltage gain A_v is defined as,

$$A_v = \frac{\Delta V_{CE}}{\Delta V_{BE}} = \frac{\text{change in load voltage}}{\text{change in input voltage}}$$

The power gain is defined as, $A_p = A_i \times A_v$

Applications of transistors

Transistors can be used as an amplifier or an oscillator.

The process of increasing the amplitude of input signal without distorting its wave shape and without changing its frequency is known as amplification.

Oscillator is device which delivers a.c. output wave form of desired frequency from d.c. power even without input signal excitation.

CHECK Point

☛ **Why is a transistor so called ?**

SOLUTION

The word Transistor can be treated as short form of two words 'transfer + resistor'. In a transistor, a signal is introduced in the low resistance circuit and output is taken across the high resistance circuit. Thus, a transistor helps to transfer the current from low resistance part to the high resistance part.

CHECK Point

☛ **The base region of a transistor is lightly doped. Explain why?**

SOLUTION

In a transistor, the majority carriers (holes or electrons) from emitter region move towards the collector region through base. If base is made thick and highly doped, then majority of carriers from emitter will combine with the carriers in the base and only small number of carriers will reach the collector. Thus the output or collector current will be considerably small. To get large output or collector current, base is made thin and lightly doped so that only few electron-hole combination may take place in the base region.

CHECK Point

☛ **Explain why the emitter is forward biased and the collector is reverse biased in a transistor ?**

SOLUTION

In a transistor, the charge carriers move from emitter to collector. The emitter sends the charge carriers and collector collects them. This can happen only if emitter is forward biased and the collector is reverse biased so that it may attract the carriers.

LAWS OF BOOLEAN ALGEBRA

Basic OR, AND, and NOT operations are given :

OR	AND	NOT
$A+0=A$	$A.0=0$	$A+\bar{A}=1$
$A+1=1$	$A.1=A$	$A.\bar{A}=0$
$A+A=A$	$A.A=A$	$\bar{\bar{A}}.A=A$

Boolean algebra obeys commutative, associative and distributive law as given below:

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Commutative laws :

$A + B = B + A$

$A . B = B . A$

Associative laws :

$A + (B + C) = (A + B) + C$

$A . (B . C) = (A . B) . C$

Distributive laws :

$A . (B + C) = A.B + A.C$

Some other useful identities :

(i) $A + AB = A$ (ii) $A . (A + B) = A$ (iii) $A + (\bar{A}B) = A + B$

(iv) $A . (\bar{A} + B) = A . B$ (v) $A + (B . C) = (A + B) . (A + C)$ (vi) $(\bar{A} + B).(A + C) = \bar{A}.C + B.A + B.C$

De Morgan's theorem :

First theorem : $\overline{A + B} = \bar{A}.\bar{B}$

Second theorem : $\overline{A.B} = \bar{A} + \bar{B}$

LOGIC GATES

- A logic gate is a digital circuit which is based on certain logical relationship between the input and the output voltages of the circuit.
- The logic gates are built using the semiconductor diodes and transistors.
- Each logic gate is represented by its characteristic symbol.
- The operation of a logic gate is indicated in a table, known as truth table. This table contains all possible combinations of inputs and the corresponding outputs.
- A logic gate is also represented by a Boolean algebraic expression. Boolean algebra is a method of writing logical equations showing how an output depends upon the combination of inputs. Boolean algebra was invented by George Boole.

There are three basic logic gates. They are (i) AND gate (ii) OR gate (iii) NOT gate

AND Gate : The output is high, when all inputs are high.

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Logic Symbol

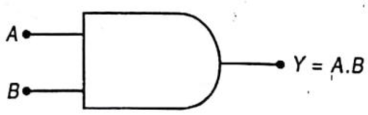


Fig. 10.24

Boolean Expression : $Y = A.B$

OR gate : Ouput is high even if one of the inputs is high.

Truth Table :

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Logic Symbol

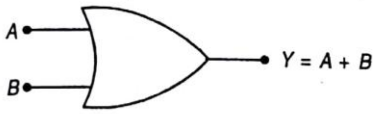


Fig. 10.25

Boolean Expression : $Y = A + B$

NOT gate : Output is not the input.

Truth Table:

A	Y
0	1
1	0

Logic Symbol

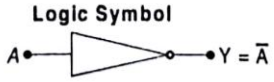


Fig. 10.26

Boolean Expression : $Y = \bar{A}$

Other logic gates

The NAND gates : The output is high, even if all inputs are low or one input is low.

Truth Table:

A	B	Y
0	0	1
1	0	1
0	1	1
1	1	0

Logic Symbol

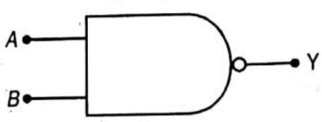


Fig. 10.27(a)

Boolean expression : $\overline{A.B} = Y$

The NOR gate : The output is high, when all inputs are low.

Truth Table:

A	B	Y
0	0	1
1	0	0
0	1	0
1	1	0

Logic Symbol

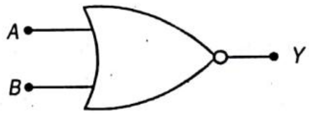


Fig. 10.27(b)

Boolean expression : $\overline{A + B} = Y$

Exclusive OR Gate :

The output of a two input Exclusive OR gate is at logical 1 if one and only one input accepts logical 0 (zero)

Symbol:

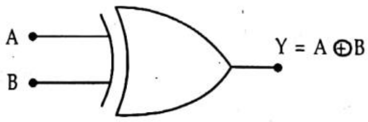


Fig. 10.28

Boolean expression : : $Y = A + B$

Truth Table

Input		Output
A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

NOTE: This circuit is also called inequality comparator or detector because it produces an output only when the two inputs are different.

- **NAND Gate is called the building block of all digital circuits.**

MISCELLANEOUS SOLVED EXAMPLES

1. In the binary number system 100 + 1011 is equal to

(a) 1000 **(b) 1011** **(c) 1110** **(d) 1111**

Sol. $(100)_2 + (1011)_2 = (0\times2^0 + 0\times2^1 + 1\times2^2) + (1\times2^0 + 1\times2^1 + 0\times2^2 + 1\times2^3)$

$= (0+0+4) + (1+2+0+8) = (15)_{10} = (1111)_2$

or $0100 + 1011 = 1111$

2. Identify the gate represented by the block diagram of Fig. Write the Boolean expression and truth table.

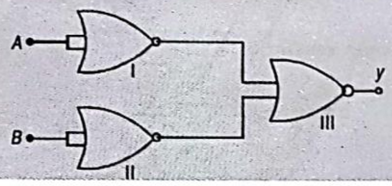


Fig. 10.29

Sol. Here for the input, the two NOR gates have been used as NOT gates (by joining the input terminals of NOR gate). Their outputs are jointly fed to the NOR gate. From the NOR gate I, for the input A, the output is $\overline{A}$. From the NOR gate II, for the input B, the output is $\overline{B}$. From NOR gate III, the output is given by $Y = \overline{\overline{A}+\overline{B}} = A.B$

Thus. Boolean expression for this combination of gate is $Y = \overline{\overline{A}+\overline{B}} = A.B$

which is for AND gate. Thus, the combination will work as AND gate. The truth table of the combination of gates is shown in Fig.

A	B	$\overline{A}$	$\overline{B}$	Y
0	0	1	1	0
1	0	0	1	0
0	1	1	0	0
1	1	0	0	1

3. The combinations of the 'NAND' gates shown here in fig. 10.30 are equivalent to

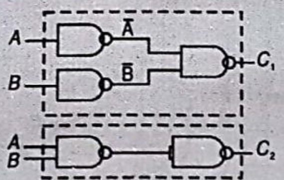


Fig. 10.30

(a) an 'OR' gate and an 'AND' gate respectively
(b) an 'AND' gate and a 'NOT' gate respectively
(c) an 'AND' gate and an 'OR' gate respectively
(d) an 'OR' gate and a 'NOT' gate respectively

Sol. For first case, $C_1 = \overline{\overline{A}.\overline{B}} = (A+B)$ (by Demorgan's Theorem)

The truth table is shown below

A	B	$\overline{A}$	$\overline{B}$	$\overline{A}.\overline{B}$	$\overline{\overline{A}.\overline{B}}$
1	0	0	1	0	1
0	1	1	0	0	1
0	0	1	1	1	0
1	1	0	0	0	1

This is truth table for $C_1 = A + B$ i.e., OR gate

For second case, $C_2 = \overline{\overline{A.B}} = A.B$ i.e., AND gate.

4. The diagram of a logic circuit is given below. The output F of the circuit is represented by

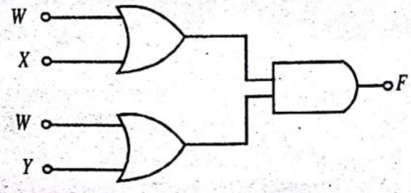


Fig. 10.31

(a) $W.(X+Y)$ (b) $W.(X.Y)$ (c) $W+(X.Y)$ (d) $W+(X+Y)$

Sol. (c) $(W+X).(W+Y)=W+(X.Y)$

5. The following configuration of gate is equivalent to

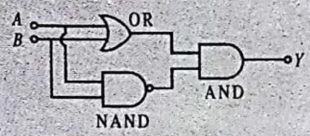


Fig. 10.32

(a) NAND (b) XOR (c) OR (d) NOR

Sol. (b)

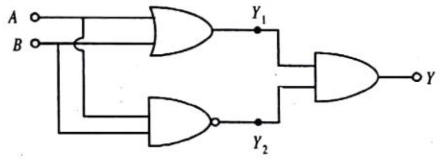


Fig. 10.33

$Y_1 = A+B,\ Y_2 = \overline{A.B}$

$Y = (A+B)\cdot\overline{AB} = A\cdot\overline{A} + A\cdot\overline{B} + B\cdot\overline{A} + B\cdot\overline{B} = 0 + A\cdot\overline{B} + B\cdot\overline{A} + 0 = A\cdot\overline{B} + B\cdot\overline{A}$

This expression is for XOR

6. Following diagram performs the logic function of

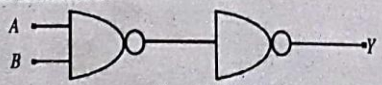


Fig. 10.34

(a) XOR gate (b) AND gate (c) NAND gate (d) OR gate

Sol. (b)

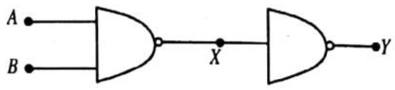


Fig. 10.35

$X = \overline{AB}$

$\therefore Y = \overline{X} = \overline{\overline{AB}}$

$Y = AB$ by Demorgan theorem

$\therefore$ This diagram performs the function of AND gate.

7. In the following circuit, the output Y for all possible inputs A and B is expressed by the truth table.

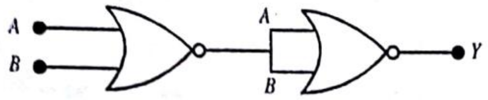


Fig. 10.36

(a)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(b)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(c)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

(d)

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Sol.

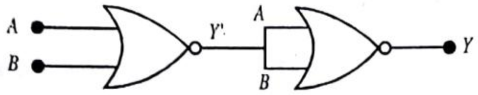


Fig. 10.37

$Y' = \overline{A+B}$. $Y = \overline{\overline{A+B}} = A+B$.

Truth table of the given circuit is given by

A	B	Y'	Y
0	0	1	0
0	1	0	1
1	0	0	1
1	1	0	1

8. The real time variation of input signals *A* and *B* are as shown below. If the inputs are fed into NAND gate, then select the output signal from the following.

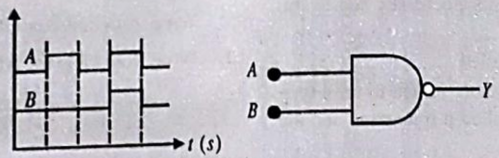
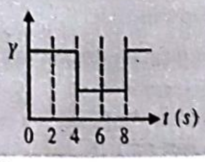
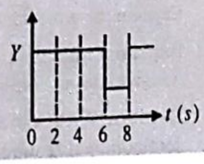


Fig. 10.38

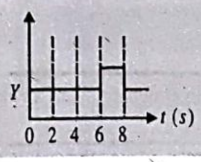
(a)



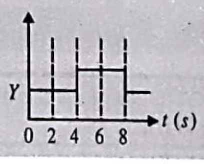
(b)



(c)



(d)



Sol. (b) From input signals, we have,

A	B	Output NAND gate
0	0	1
1	0	1
0	0	1
1	1	0
0	0	1

The output signal is shown at *B*.

1 EXERCISE

FIB Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. In a reverse biased p-n junction diode, the p-type semiconductor is connected to .... terminal of the cell and n-type to the .... terminal of the cell.
2. A group of 8 bits is called a ....
3. The depletion region in a semiconductor diode is formed at the ....
4. The process of introducing impurities in small quantities into intrinsic semiconductor is called ....
5. The substances whose electrical conductivity lies between conductors and insulators are called ....,
6. The conductivity of semiconductor is of the order of ....
7. The conductivity of semiconductor increases with .... in temperature.
8. In semiconductors, electrical conduction is due to ....
9. Semiconductors have .... temperature coefficient of resistance.
10. The resistance of semiconductors decreases due to the addition of ....
11. A semiconductor in pure form is called ....
12. If a p-type semiconductor is suitably joined to an n-type semiconductor, the junction is called p-n junction and the device so formed is called.................

T/F True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Addition of either trivalent or pentavalent impurities to an intrinsic semiconductor increases its conductivity.
2. The electric current in an extrinsic semiconductor is the sum of currents due to holes and electrons.
3. In conductors, the valence and conduction bands may overlap.
4. Substances with energy gap of the order of 10 eV are insulators.
5. The resistivity of a semiconductor increases with increase in temperature.
6. The conductivity of a semiconductor increases with increase in temperature.
7. Transistors require long warm ups than vacuum tubes.
8. Vacuum tubes are more resistant in shocks and vibrations than transistors
9. The base of a transistor is made very thin and highly doped.
10. In a transistor, both the emitter and collector are equally doped.

VSAQ Very Short Answer Questions :

DIRECTIONS : *Give answer in one word or one sentence.*

1. What is an amplifier?
2. What is the effect of temperature on semiconductor?
3. What is a diode?
4. What is an extrinsic semiconductor?
5. What is doping?
6. What is a hole?
7. What is a p-n junction?
8. What is rectifier?
9. Write truth table for OR gate.
10. Write truth table for AND gate.

LAQ Long Answer Questions :

DIRECTIONS : *Give answer in four to five sentences.*

1. Explain the working of p-n-p transistor.
2. Explain with a neat circuit diagram the working of *n-p-n* transistor as an amplifier.
3. Explain with a neat circuit diagram the action of semiconducting diode as a half wave rectifier.
4. What is logic gate? Explain the following gates.
   (i) OR gate (ii) AND gate
   (iii) NAND gate
5. What is a transistor? Explain its types.

2 EXERCISE

Multiple Choice Questions :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

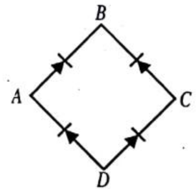
1. *p-n* junction is said to be forward biased, when
   (a) the positive pole of the battery is joined to the *p*-semiconductor and negative pole to the n-semiconductor
   (b) the positive pole of the battery is joined to the *n*-semiconductor and p-semiconductor
   (c) the positive pole of the battery is connected to *n*- semiconductor and p- semiconductor
   (d) a mechanical force is applied in the forward direction
2. At absolute zero, Si acts as
   (a) non-metal (b) metal
   (c) insulator (d) none of these
3. When *n*-type semiconductor is heated
   (a) number of electrons increases while that of holes decreases
   (b) number of holes increases while that of electrons decreases
   (c) number of electrons and holes remain same
   (d) number of electrons and holes increases equally.
4. The following truth table corresponds to the logic gate

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

   (a) NAND (b) OR
   (c) AND (d) XOR
5. To use a transistor as an amplifier
   (a) The emitter base junction is forward biased and the base collector junction is reverse biased
   (b) no bias voltage is required
   (c) both junctions are forward biased
   (d) both junctions are reverse biased.
6. For amplification by a triode, the signal to be amplified is given to
   (a) the cathode (b) the grid
   (c) the glass-envelope (d) the anode
7. The part of the transistor which is heavily doped to produce large number of majority carriers is
   (a) emitter
   (b) base
   (c) collector
   (d) any of the above depending upon the nature of transistor
8. When a *p-n* junction diode is reverse biased the flow of current across the junction is mainly due to
   (a) diffusion of charges
   (b) drift of charges
   (c) depends on the nature of material
   (d) both drift and diffusion of charges
9. What is the value of $A+\overline{A}$ in the Boolean algebra ?
   (a) 0 (b) 1
   (c) A (d) $\overline{A}$
10. Which of the following gates corresponds to the truth table given below?

A	B	Y
1	1	0
1	0	1
0	1	1
0	0	1

   (a) NAND (b) OR
   (c) AND (d) XOR
11. In the diagram, the input is across the terminals A and C and the output is across B and D. Then the output is



   (a) zero (b) same as the input
   (c) full wave rectifier (d) half-wave rectifier
12. Which of the following, when added as an impurity, into the silicon, produces *n*-type semi-conductor?
   (a) Phosphorous (b) Aluminium
   (c) Magnesium (d) Both b and c
13. When an *n–p–n* transistor is used as an amplifier then
   (a) the electrons flow from emitter to collector
   (b) the holes flow from emitter to collector
   (c) the electrons flow from collector to emitter
   (d) the electrons flow from battery to emitter
14. When arsenic is added as an impurity to silicon, the resulting material is
   (a) *n*-type semiconductor
   (b) *p*-type semiconductor
   (c) *n*-type conductor
   (d) insulator

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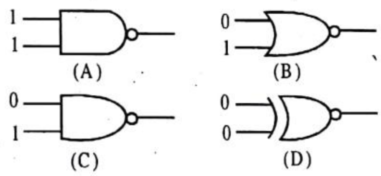
15. To obtain a p-type germanium semiconductor, it must be doped with
(a) arsenic (b) antimony
(c) indium (d) phosphorus

16. The following truth table belongs to which of the following four gates?

A	B	Y
1	1	0
1	0	0
0	1	0
0	0	1

(a) NOR (b) XOR
(c) NAND (d) OR

17. Which of the following gates will have an output of 1?



(a) D (b) A
(c) B (d) C

18. A gate has the following truth table.

P	Q	R
1	1	1
1	0	0
0	1	0
0	0	0

The gate is
(a) AND (b) NOR
(c) OR (d) NAND

19. Which gate is represented by the following truth table ?

A	B	Y
0	0	1
1	0	1
0	1	1
1	1	0

(a) XOR (b) NOT
(c) NAND (d) AND

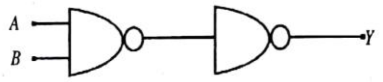
20. The intrinsic semiconductor becomes an insulator at
(a) $0°C$ (b) 0 K
(c) 300 K (d) $-100°C$

21. In a p-n junction
(a) The potential of the p and n-sides becomes higher alternately
(b) The p-side is at higher electrical potential than the n-side
(c) The n-side is at higher electrical potential than the p-side
(d) Both the p and n-sides are at the same potential

22. An n-p-n transistor conducts when
(a) both collector and emitter are negative with respect to the base
(b) both collector and emitter are positive with respect to the base
(c) collector is positive and emitter is negative with respect to the base
(d) collector is positive and emitter is at same potential as the base

23. Barrier potential of a p-n junction diode does not depend on
(a) doping density (b) diode design
(c) temperature (d) forward bias

24. Following diagram performs the logic function of



(a) XOR gate (b) AND gate
(c) NAND gate (d) OR gate

25. Reverse bias applied to a junction diode
(a) increases the minority carrier current
(b) lowers the potential barrier
(c) raises the potential barrier
(d) increases the majority carrier current

26. In semiconductors, at room temperature
(a) the conduction band is completely empty
(b) the valence band is partially empty and the conduction band is partially filled
(c) the valence band is completely filled and the conduction band is partially filled
(d) the valence band is completely filled

27. The output of OR gate is 1
(a) if either input is zero
(b) if both inputs are zero
(c) if either or both inputs are 1
(d) only if both inputs are 1

28. Application of a forward bias to a p–n junction
(a) widens the depletion zone.
(b) increases the potential difference across the depletion zone.
(c) increases the number of donors on the n side.
(d) increases the electric field in the depletion zone.

29. Zener diode is used for
(a) Amplification
(b) Rectification
(c) Stabilisation
(d) Producing oscillations in an oscillator

30. When the temperature of a semiconductor is increased, its electrical conductivity
(a) increases
(b) decreases
(c) remains the same
(d) increases at first and then decreases

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31. A piece of copper and another of germanium are cooled from room temperature to 80 K. The resistance of
(a) each of them increases
(b) each of them decreases
(c) copper increases and germanium decreases
(d) copper decreases and germanium increases

32. At absolute zero temperature, a crystal of pure germanium.
(a) behaves as perfect conductor
(b) behaves as perfect insulator
(c) contains no electron
(d) none of the above

33. In an intrinsic semiconductor
(a) only electrons are responsible for flow of current
(b) both holes and electrons carry current
(c) both holes and electrons carry current with electrons being majority carriers
(d) only holes are responsible for flow of current

34. A ordinary temperature, an increase in temperature increases the conductivity of
(a) conductor (b) semiconductor
(c) insulator (d) alloy

35. If the conductivity of a semiconductor is only due to break up of the covalent bonds due to thermal excitation, then the semiconductor is called
(a) intrinsic (b) extrinsic
(c) donor (d) acceptor

36. In a good conductor the number of electrons in the valence shell, in general, is
(a) less than 4 (b) more than 4
(c) equal to 4 (d) none of these

37. The mobility of conduction electrons is greater than that of holes, since electrons
(a) are lighter
(b) are negatively charged
(c) require smaller energy for moving through crystal lattice
(d) undergo smaller number of collisions

38. The majority of current carriers in an n-type semiconductor are
(a) holes (b) electrons
(c) negative ions (d) positive ions

39. A hole in p-type semiconductor is
(a) an excess electron (b) a missing electron
(c) a missing atom (d) a donor level

40. An n-type semiconductor is
(a) negatively charged
(b) positively charged
(c) neutral
(d) negatively or positively charged depending upon the amount of impurity

41. A hole in a semiconductor
(a) has zero mass
(b) has mass equal to that of proton
(c) has mass equal to that of positron
(d) is a positively charged vacancy

42. The conductivity of a pure semiconductor can be increased by
(a) increasing temperature
(b) mixing trivalent impurity
(c) mixing pentavalent impurity
(d) all of the above

43. In p-type semiconductor the majority and minority charge carriers are respectively
(a) protons and electrons
(b) electrons and protons
(c) electrons and holes
(d) holes and electrons

44. When boron is added as an impurity to silicon, the resulting material is
(a) n-type semiconductor
(b) n-type conductor
(c) p-type conductor
(e) p-type semiconductor

45. The depletion layer in the p-n junction is caused by
(a) drift of holes
(b) diffusion of charge carriers
(c) migration of impurity ions
(d) drift of electrons

46. The small currentsin reverse bias condition are due to :
(a) electrons
(b) majority charge carriers, i.e., electrons on n-side and holes on p-side
(c) minority charge carriers, i.e., electrons on p-side and holes on n-side.
(d) temperature

47. The doping of the base of a transistor is :
(a) equal to that of emitter or collector
(b) slightly more than that of emitter or collector
(c) less than that of emiiter or collector
(d) much more than that of emitter or collector

48. In the symbol of a transistor, the arrow head points in the direction of flow of
(a) holes
(b) electrons
(c) majority carriers
(d) minority carriers

49. Transistors are essentially
(a) power driven devices
(b) current driven devices
(c) voltage driven devices
(d) resistance driven devices

50. In a transistor
(a) emitter is more highly doped than collector
(b) collector is more highly doped than emitter
(c) both are equally doped
(d) none of the above

51. In a transistor
(a) length of emitter is greater than that of collector
(b) length of collector is greater than that of emiter
(c) length of base is greater than that of emitter
(d) length of base is greater than that of collector

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52. One way in which the operation of an n-p-n transistor differs from that of a p-n-p
   (a) the emitter junction is reverse biased in n-p-n.
   (b) the emitter junction injects minority carriers into base region of the p-n-p
   (c) the emitter injects holes into the base of the p-n-p and electrons into the base region n-p-n
   (d) the emitter injects holes into the base of n-p-n

53. n-p-n transistors are preferred to p-n-p transistors because:
   (a) they have low cost
   (b) they have low dissipation energy
   (c) they are capable of handling large power
   (d) electrons have high mobility than holes and hence high mobility of energy

A&R Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by Reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) If **Assertion** is **correct** but **Reason** is **incorrect.**
(d) If **Assertion** is **incorrect** but **Reason** is **correct.**

1. **Assertion :** NAND or NOR gates are called digital building blocks.
   Reason : The repeated use of NAND (or NOR) gates can produce all the basis or complicated gates.
2. **Assertion :** When two semi conductor of p and n type are brought in contact, they form p-n junction which act like a rectifier.
   Reason : A rectifier is used to convent alternating current into direct current.
3. **Assertion :** NOT gate is also called invertor circuit.
   Reason : NOT gate inverts the input order.
4. **Assertion:** In common base configuration, the current gain of the transistor is less than unity.
   Reason: The collector terminal is reverse biased for amplification.
5. **Assertion:** A p-n junction with reverse bias can be used as a photo-diode to measure light intensity.
   Reason: In a reverse bias condition the current is small but is more sensitive to changes in incident light intensity.

HOTS Subjective Questions :

DIRECTIONS : *Answer the following questions.*

1. Frequency of input voltage of a half-wave rectfier is 50 Hz. What will be the frequency of the output voltage.
2. How is a sample of n-type semiconductor electrically neutral though it has an excess of negative charge carriers?
3. Using a suitable combination from a NOR, an OR and a NOT gate, draw circuits to obtain the truth table given below:

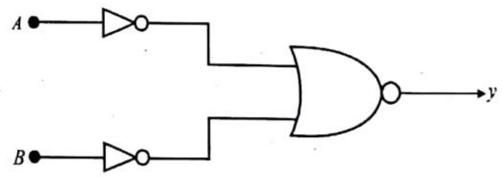
A	B	Y
0	0	0
0	1	0
1	0	1
1	1	0

(i)

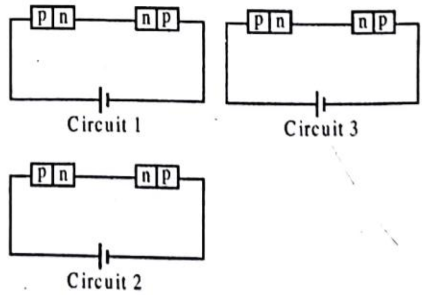
A	B	Y
0	0	1
0	1	1
1	0	0
1	1	1

(ii)

4. Give reasons :
   (i) Why common emitter circuit is used for making an oscillator.
   (ii) Why common emitter amplifier is preferred over common base amplifier.
5. The output of two NOT gates is made input for NOR gate. Name the new logic gate obtained and write down its truth table.



6. Two identical p-n junctions may be connected in series with a battery in three different ways as shown in the circuit diagrams. In which circuit diagrm will the potential drop across the p-n junctions be equal?



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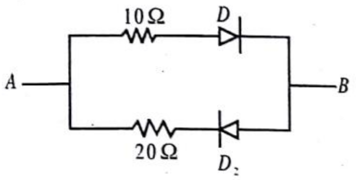
7. What is the resistance offered by the following circuit if the current flows from

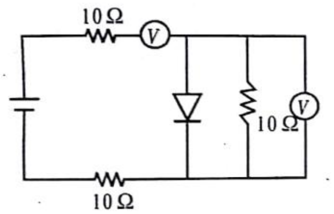
(1) A to B and (2) B to A?

Assume the diodes to be ideal.

Whath is the PD across D_1 and D_2, when they were non-conducting, i.e., when they are reverse biased, if $7V$ is applied across AB?



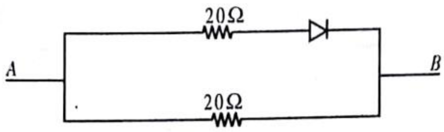
8. In the following circuit diagram, if the diode is ideal, what are the values recorded by the ammeter and the voltmeter?



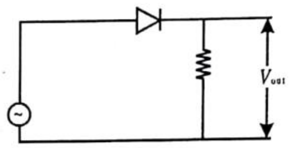
9. What is the resistance offered by the following circuit if current flows from

(1) A to B and (2) B to A?

(Assume diode to be an ideal diode)

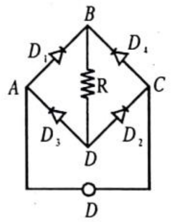


10. An AC voltage is applied to the diode, as shown in the figure below. Draw the graph of output voltage versue time. Explain the action of the diode.



Is the output voltage across R a DC voltage? Explain.

11. In the following circuit, explain the flow of current through resistor R. Can we use the circuit to convert AC to DC? Explain.



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SOLUTIONS

Brief Explanations of Selected Questions

Exercise 1

FILL IN THE BLANKS :

1. negative, positive
2. byte
3. junction
4. doping
5. semiconductors
6. 1 $ohm^{-1} m^{-1}$
7. increase
8. electrons and holes
9. negative
10. impurities
11. intrinsic semiconductor
12. diode

TRUE / FALSE

1. True 2. True 3. True 4. True
5. False 6. True 7. False 8. False
9. False 10. False

VERY SHORT ANSWER QUESTIONS :

1. A circuit which strengthens weak AC signals.
2. Conductivity increases with increase in temperature.
3. (i) A *p-n* junction.
   (i) Unidirectional flow of current.
4. Impure semiconductor.
5. Addition of impurities to a pure semiconductor.
6. Vacant site created in the VB when electrons jump from VB to CB.
7. A junction between a *p*-type and *n*-type semiconductor such that it is continuous at the boundary.
8. A circuit which converts AC into DC.

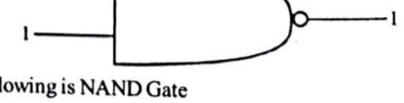
VERY SHORT ANSWER QUESTIONS :

1. Emitter base junction is forward biased and collector base junction is reverse biased.
2. Large output voltage drop across load resistor.
3. Diode conducts when it is forward biased.

Exercise 2

MULTIPLE CHOICE QUESTIONS :

1. (a) For forward biasing of *p-n* junction, the positive terminal of external battery is to be connected to *p*-semiconductor and negative terminal of battery to the n-semiconductor.
2. (c) Semiconductors are insulators at room temperature.
3. (d) Due to heating, when a free electron is produced then simultaneously a hole is also produced.
4. (b) This truth table is of identity, $y = A + B$, hence. OR gate.
5. (a) To use a transistor as an amplifier the emitter base junction is forward biased while the collector base junction is reverse biased.
6. (b) The amplifying action of a triode is based on the fact that a small change in grid voltage causes a large change in plate current. The AC input signal which is to be amplified is superimposed on the grid potential.
7. (a) The function of emitter is to supply the majority carriers. So, it is heavily doped
8. (b) When *p-n* junction is reverse biased, the flow of current is due to drifting of minority charge carriers across the junction.
9. (b) When A = 1, then $A + \overline{A} = 1 + 0 = 1$
   and when A = 0, then $A + \overline{A} = 0 + 1 = 1$
10. (c) This truth table is of the identity, $y = \overline{A.B}$, hence, it is NAND gate.
    Here, the output is high even if all inputs are low or one input is low.
11. (c) the given circuit is a circuit of full wave rectifier.
12. (a) Phosphorous (P) is pentavalent and silicon is tetravalent. Therefore, when silicon is doped with pentavalent impurity, it forms a n-type semiconductor.
13. (a) In an *n-p-n* transistor, the charge carriers, are free electrons in the transistor as well as in external circuit; these electrons flow from emitter to collector.
14. (a) Arsenic contains 5 electrons in its outermost shell. When Arsenic is mixed with silicon there is one electron extra in silicon crystal. Hence, such type of semi conductor is *n*-type semiconductor.
15. (c) *p*-type germanium semiconductor is formed when it is doped with a trivalent impurity atom.
16. (a) The given truth table is of
    (OR gate + NOT gate) $\equiv$ NOR gate
17. (d) (a) is a NAND gate so output is $\overline{1\times1} = \overline{1} = 0$
    (b) is a NOR gate so output is $\overline{0+1} = \overline{1} = 0$
    (c) is a NAND gate so output is $\overline{0\times1} = \overline{0} = 1$
    (d) is a XOR gate so output is $0 \oplus 0 = 0$



Following is NAND Gate
$Y = \overline{A.B}$

18. (a) P, Q and R are related as $R = P.Q$ which is relation of AND gate.

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19. (c) $Y = \overline{A.B}$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Which is truth table of NAND gate.

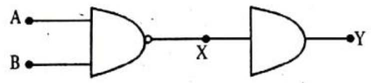
20. (a) At 0K, motion of free electrons stop. Hence conductivity becomes zero. Therefore, at 0K intrinsic semiconductor becomes insulator.

21. (b) For conduction, *p-n* junction must be forward biased. For this *p*-side should be connected to higher potential and *n*-side to lower potential.

22. (c) When the collector is positive and emitter is negative w.r.t. base, it causes the forward biasing for each junction. which causes conduction of current.

23. (b) Barrier potential does not depends on diode design while barrier potential depends upon temperature, doping density, and forward biasing.

24. (b)



$X = \overline{A.B}$

$\therefore Y = \overline{X} = \overline{\overline{A.B}}$

Y = A. B by Demorgan therorem

$\therefore$ This diagram performs the function of AND gate.

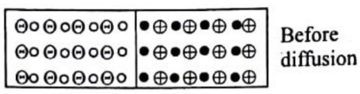
25. (c) In reverse biasing, the conduction across the *p-n* junction does not take place due to majority carriers but takes place due to minority carriers if the voltage of external battery is large. The size of the depletion region increases thereby increasing the potential barrier.

26. (c) In semiconductros, the conduction is empty and the valence band is completely filled at 0 K. No electron from valence band can cross over to conduction band at 0K. But at room temperature some electrons in the valence band jump over to the conduction band due to the small forbidden gap, *i.e.* 1 eV.

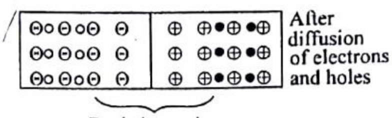
27. (c) Output will be one if *A* or *B* or both are one $Y = A + B$

28. (c)

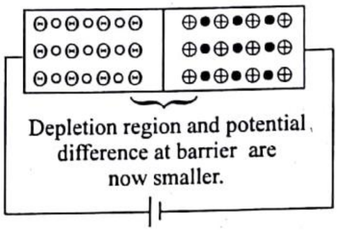
PN



• Solid dot = electron
o Hollow circle = hole



Depletion region



Number of donors is more because electrons from -ve terminal of the cell pushes (enters) the n side and decreases the number of uncompensated pentavalent ion due to which potential barrier is reduced. The neutralised pentavalent atom are again in position to donate electrons.

29. (c) At a certain reverse bias voltage, zener diode allows current to flow through it and hence, maintains the voltage supplied to any load Hence it is used for stabilisation.

30. (a) **31.** (d) **32.** (b) **33.** (b) **34.** (b)
35. (a) **36.** (a) **37.** (c) **38.** (b)
39. (b) In a *p*-type semiconductor, a hole is a missing elec tron in a covalent bond.
40. (c) **41.** (d) **42.** (d) **43.** (d) **44.** (d)
45. (b) **46.** (c) **47.** (c) **48.** (a) **49.** (b)
50. (a) **51.** (b) **52.** (c) **53** (d)

Assertion & Reason :

1. (b) These gates are called digital building blocks because using these gates only (either NAND or NOR) we can compile all other gates also (like OR, AND, NOT, XOR)

2. (c) Study of junction diode characteristics shows that the junction diode offers a low resistance path, when forward biased and high resistance path when reverse biased. This feature of the junction diode enables it to be used as a rectifier.

3. (b) A NOT gate puts the input condition in the opposite order, means for high input it give low output and for low input it give high output. For this reason NOT gate is known as invertor circuit.

4. (c) Assertion is true but reason is false.

The common base configuration of *n-p-n* transistor is used for voltage amplification. The current amplification is very small.

Assertion is true.

the collector is reverse biased for voltage amplification. The reason given has not mentioned that it is voltage amplification. The reason is therefore, incomplete by itself. It is wrong.

5. (a)

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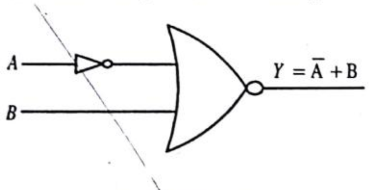
HOTS SUBJECTIVE QUESTIONS :

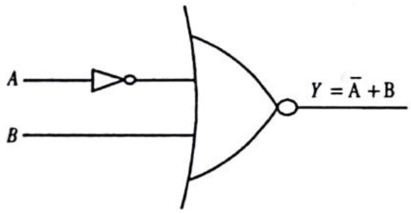
1. 50 Hz.
2. An n-type semiconductor is obtained by doping pure Si or Ge crystal with pentavalent impurity. As the impurity atoms enter into the configuration of the Si crystal, its four electrons take part in covalent bonding, while the fifth electron is left free.

   But each atom of the semiconductor as a whole is electrically neutral, the n-type Ge crystal is electrically neutral.
3. (i) Circuit diagram for truth table (i)



A	B	$\bar{A}$	$\bar{A}+B$	$Y=\overline{\bar{A}+B}$
0	0	1	1	0
0	1	1	1	0
1	0	0	0	1
1	1	0	1	0

(ii) Circuit diagram for truth table (ii)

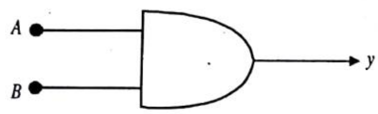


A	B	$\bar{A}$	$Y=\bar{A}+B$
0	0	1	1
0	1	1	1
1	0	0	0
1	1	0	1

4. (i) For positive feedback

   (ii) More gain (current, voltage and power)
5. $y=\overline{\bar{A}+\bar{B}}=\bar{\bar{A}}.\bar{\bar{B}}=A.B$

   Hence, AND gate is formed.



A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

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